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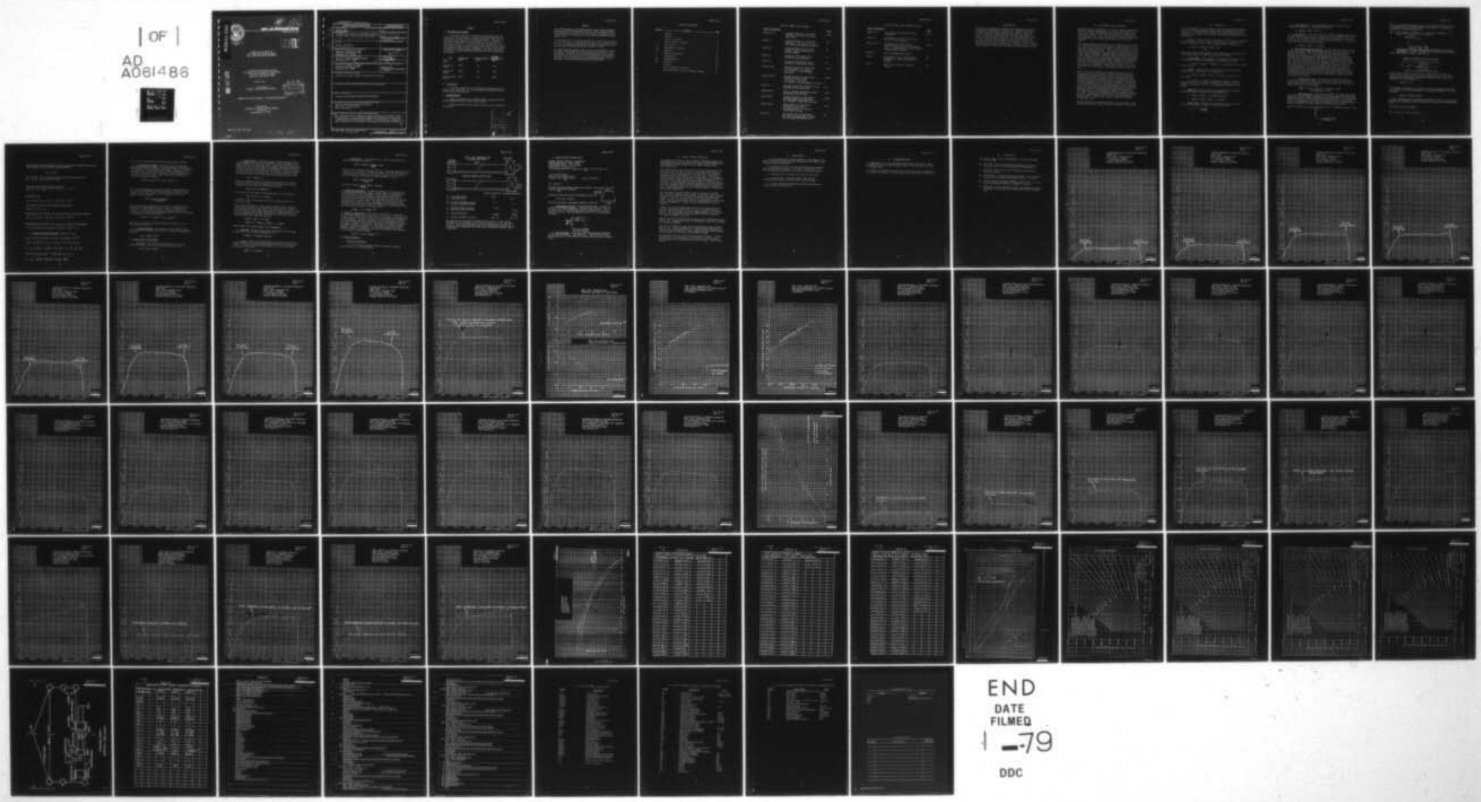

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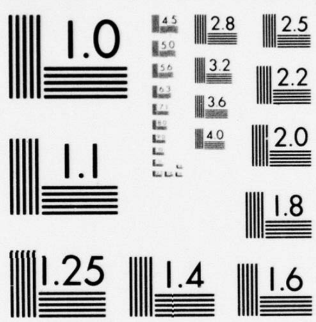

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NAVAL AIR ENGINEERING CENTER

REPORT NAEC-91-7927

Lakehurst, NJ
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A STUDY OF THE EFFECT OF DIFFERENT CAM DESIGNS ON MARK 7 MOD 1 ARRESTING GEAR PERFORMANCE

Launching and Recovery Division
Ship Installations Engineering Department
Naval Air Engineering Center
Lakehurst, New Jersey 08733

2 AUGUST 1978

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This report develops a hydraulic simulation program for the Mark 7 Mod 1 Arresting Gear. It also compares theoretical performance with aircraft arrestments using different cam profiles. The present cam, rotated on its dwell, provides as much hydraulic load reduction as any new cam design.

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SUMMARY

A. PROCEDURES AND RESULTS

1. In order to predict the theoretical performance of the Mark 7 Mod 1 Arresting Gear, a computer program was written that attempted to simulate actual recovery operations. The output of this program was compared to experimental results in order to verify its reliability. Once this check was accomplished, new cam designs as well as the existing K-5 cam, rotated on its dwell, were used as inputs in order to compare the effects of each set of coordinates on recovery gear performance. The table below lists the results for peak operating conditions with the corresponding ram strokes.

CAM	WEIGHT (LBS)	VELOCITY (KNOTS)	CYLINDER PRESSURE (PSI)
K-5 (118")	50000	111	10000
Rotated K-5 (122")	50000	111	9600
Rotated K-5 (126")	50000	111	9200
New Cam Design (122")	50000	111	9600

B. CONCLUSIONS

1. Since the rotated K-5 cam provides the same reduction in load as a new cam design, it is not necessary to replace the existing K-5 cam with any new cam.

C. RECOMMENDATIONS

1. Adopt the procedure for rotating cams as outlined in Mark 7 Service Bulletin 300 to all Mark 7 Mod 1 ships.

2. Study the effect of cam rotation on Mark 7 Mod 2 and Mark 7 Mod 3 ships.

PREFACE

The arresting gear systems aboard present ships contain hydraulic engines that develop retarding forces to arrest landing aircraft. The cams, which are driven by the ram stroke of the engine, act as control devices in regulating the fluid flow through the constant runout valve.

The present Mark 7 Mod 1 Arresting Gear has a 118.1-inch ram stroke, at 18:1 reeve ratio, a deck span of 95 feet, and is equipped with a K-5 cam. The maximum allowable MEC pressure is 10,000 psi, and it has an energy absorbing capacity of 31 x 10^6 ft-lbs.

The upper balanced constant runout valve insures positive closure and allows for extended ram travel through a rotated cam or new cam design. After the 122-inch radial coordinate, cable stretch provides payout which can be used by rotating the cam to the 126-inch mark. This study shows how the additional service stroke increases the energy absorbing capability of the gear.

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I. INTRODUCTION

This study is intended to investigate the feasibility of new cam configurations aboard Mark 7 Mod 1 ships. Present cam contours on these ships have service strokes of 118. inches. There is, however, within the engine framework additional available ram travel that had been previously used for cross-head battery position and two-block safety distance. Since the installation of the upper balanced control valve insures positive closure and limited ram overtravel, allowances for crosshead battery positioning and two-block safety distance can be reduced. Thus, in effect, usable engine ram travel can be increased for operational purposes.

II. EQUIPMENT AND PROCEDURES

The first step in this study was to write a computer program that simulated aircraft arrestments. To do this, the layout of the Mark 7 Mod 1 gear was drawn and the interaction of the various components analyzed. Once these descriptions and interactions were understood, they were formulated into engineering equations, assembled into logical order, and detailed into a computer program.

The computer program was subject to test. Certain relationships, (i.e. mechanical efficiency and velocity coefficients) were unknown and to best approach the values of these variables, a trial and error procedure was used. That is, with the core of the program described mathematically, the unknown variables were used as inputs into the program. Repeated inputs of these variables over a wide range of aircraft velocities and weights finally evolved a set of numbers that, over a select range of aircraft arrestment histories, gave the best hypothetical simulation in comparison to the known experimental results. These "numbers" were then put into a curve-fit program and one equation for each of the relationships was formulated. Mechanical efficiency and velocity coefficients are discussed in the analysis section of this report.

Results from the program proved compatible with existing test data from the RALS. Both sets of data, the theoretical and experimental, considered the K-5 cam as part of the arresting-system configuration. The next step was to develop new cam coordinates over extended strokes and to investigate the effect of these coordinates on recovery gear performance. Various layouts were designed and the coordinates used as inputs. Because of the physical structure of the arresting gear, the tolerances needed for cross-head positioning and safety stops, and the fact that cable stretch occurs during an arrestment, the maximum "new cam design" set of coordinates could be increased to 122 vs. 118.". (Cable stretch over the next four inches and rotation of the "new cam design" would provide for the maximum service stroke of 126".) The K-5 cam could be rotated on its dwell 8" from 118 to 126".

The actual layouts of these cam designs, and the pressure cards developed from their use, are shown in the results of this study.

III. ANALYSIS

A. It is intended in this analysis to show the mathematical equations used in the computer program, a theoretical discussion of the unknown variables (i.e. mechanical efficiency, and velocity coefficient) developed in the program, and the design conditions established to improve performance.

1. RUNOUT. Aircraft runout is defined from the point of intersection of the aircraft hook to the final position where the aircraft stops. Given an engaging velocity, ACVEL, aircraft runout is defined as

a. $\text{RUNOUT} = \text{RUNOUT}_{(PT)} + \text{ACVEL} \times \text{TIME}$

where (PT) references any variable from a previous time and TIME is the incremental period over which the calculation is made.

2. CABLE LENGTH. Cable length is the measure of distance of any one cable from the point of engagement to the sheaves on deck.

a. $\text{CBLNTH} = (\text{RUNOUT}^2 + \text{HSPAN}^2)^{.5}$ where HSPAN = 1/2 the deck pendant length.

3. PAYOUT. Cable payout is the amount of cable fed from the engine that is transferred to the carrier deck.

a. CBLPOU = CBLNTH - HSPAN or in terms of cable fed from the engine.

b. CBLPOU = 2 x NSHVES x STROKE where NSHVES = number of movable sheaves any one cable is attached to, stroke is the ramstroke of the engine, and (2) is the mechanical advantage of the system.

4. RAMSTROKE. Can be defined as the distance the crosshead moves along its guided tracks and from equation 3b.

a. STROKE = CBLPOU / 2 x NSHVES and from 3a.

b. STROKE = CBLNTH - HSPAN / 2 x NSHVES

5. RUNOUT ANGLE. Knowing the runout and the length of cable on deck, from a right triangle it is easily seen that

a. $\cos(\theta) = \dfrac{\text{RUNOUT}}{\text{CBLNTH}}$

6. CABLE VELOCITY. Given an engaging velocity of the airplane as ACVEL, the velocity of the cable it hooks is

a. CBLVEL = ACVEL / COS (θ)

7. RAM VELOCITY. The cable, through a system of sheaves whose effect is neglected in this analysis, is connected to the crosshead which drives the ram. The crosshead contains 9 upper and 9 lower sheaves. One cable from the deck is reeved through one set of these sheaves in one bank, and since there are two banks per crosshead

a. RAMVEL = CBLVEL / 2 x NSHVES

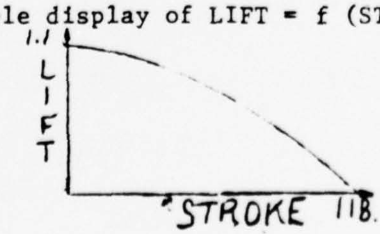
8. MAIN ENGINE CYLINDER PRESSURE. With the ram set in motion by the arresting wire rope, there is a subsequent build up of retarding "forces" within the cylinder. This force is actually the cylinder pressure applied over a unit area. The constant runout valve, the cam, and the chain drive system regulate the pressure drop from the main engine cylinder into the accumulator. The "key" to the control valve is the cam. The cam rotates on to a valve stem which fits into the valve seat and at the end of an arrestment is completely closed. The cam is driven by a chain drive which is hooked to the moving crosshead, which, as mentioned before, is driven by the engaged wire rope. Thus, there is an enclosed system. An airplane engages a wire rope which drives a crosshead which forces fluid through a control valve whose stem lift is regulated by a cam which is driven by a chain drive. Complete rotation of the cam will shut the control valve, stop the fluid flow, and bring the aircraft to a stop.

a. Control Valve Area. The cam and its rotational position determines the amount of opening in the control valve. From a geometric layout, taken over an extended series of lifts, the control valve area varies according to the following:

AREORF = 1.1107 x (LIFT) x (2 x VALDIA - LIFT)
(See NAEC MISC. 07352)

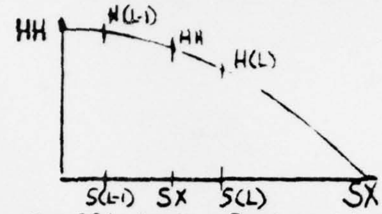
b. Valve Stem Lift. The "valve stem lift" is actually the transposition of the cam radial coordinates to the valve stem which effectively regulates cylinder pressure and closes the control valve. It is a function of the ram stroke, and is in essence the primary motive for this report. That is, to determine a set of cam coordinates that over an extended (from previous designs) ram stroke produces the optimum pressure card.

Figure 1 below gives a simple display of LIFT = f (STROKE) for the K-5 Cam.



NOTE: In the computer program, since all calculated strokes didn't have a corresponding lift from input data, it was necessary to interpolate according to the following equation:

(HH) = LIFT = (STROKE - STROKE (L - 1) / STROKE (L) - STROKE (L - 1))
x (LIFT (L) - LIFT (L - 1)) + LIFT (L - 1)



c. Discharge Coefficient, Contraction Coefficient, and Velocity Coefficient. It can be assumed that the constant runout control valve acts similar to a sharp edge orifice.

SHARP EDGED ORIFICE IN A PIPE

For this type of device the contraction coefficient is defined as CONCOF = A_2/A_o, where A_2 and A_o are the respective areas. The velocity coefficient is a measure of loss during contraction, that is, it is a function of the Reynold Number, R.

VELCOF = f (R)

The discharge coefficient is a function of both the Reynolds number and the ratio of the contraction diameter to the conduit diameter. It can be defined by

DSHCOF = CONCOF x VELCOF

In order to determine the pressure drop through the orifice it is necessary to apply these equations as well as Bernoulli's equation for incompressible flow.

Referring to the above diagram

$$V_{1t}^2 / 2g + P_1 / \varrho = V_{2t}^2 / 2g + P_2 / \varrho$$

The continuity equation relates V_{1t} and V_{2t} with the contraction coefficient That is $V_1A_1 = V_2\ A_o$ (CONCOF); setting CONCOF = C_c

$$V_1A_1 = V_2A_oC_c$$

For the Mark 7 Mod 1 it has been experimentally determined that $C_c = 1.1\ A_o - .217$ (NAEC MISC. 07262)

From continuity and Bernoulli's equation
$(P_1 - P_2)\ /\rho = (V_{2t}^2\ /\ 2g) \times (1-C_c^2\ (A_o\ /\ A_1)\ ^2)$

solving for V_{2t}

$V_{2t} = ((2g\ (P_1 - P_2)\ /\rho\ )\ /\ (1-C_c^2\ (A_o\ /\ A_1)^2)\ ^{.5}$

The actual velocity to the theoretical velocity is

VELCOF = $C_v = V_A\ /\ V_T$

multiplying by C_v to obtain the actual velocity at the vena contracta

$V_{2A} = C_v \times ((2\ (P_1 - P_2)\ /\rho)\ /\ (1-C_c{}^2\ (A_o\ /\ A_1)^2)\ ^{.5}$

Multiplying by the area of the jet $C_c \times A_o$ produces the discharge Q.

$Q = C_c\ C_v\ A_o\ ((2\ (P_1 - P_2)\ /\rho)\ /\ (1-C_c{}^2\ (A_o\ /\ A_1)\ ^2)\ .5$

d. Pressure Drop Across Orifice. Since $Q_1 = V_1\ A_1$

$V_1\ A_1 = C_c\ C_v\ A_o \times (2(\ P_1 - P_2)\ /\rho)\ /\ (1-C_c^2\ (A_o\ /\ A_1)\ ^2)^{.5}$

$V_1^2\ A_1^2 = C_c^2\ C_v{}^2\ A_o{}^2 \times (2(\ P_1 - P_2)\ /\rho)\ /\ (1-C_c{}^2\ (A_o\ /\ A_1)^2)$

$P_1 - P_2 = (\rho V_1^2/2) \times ((A_1^2/A_o^2)\ /\ (C_c^2\ \ C_v^2)) \times (1 - C_c^2\ /\ A_o^2\ /\ A_1^2))$

Since $A_1 >>>> A_o, (A_o/\ A_1)^2 \rightarrow\ 0$ and since $C_d = C_c \times C_v$

$P_1 - P_2 = (\ \rho V_1^2/2) \times (A_1^2/\ A_o^2) \times (1/C_d^2)$ = DPMEC

which is the pressure drop across the control valve orifice.

e. Accumulator Pressure. It is known for most aircraft arrestments, that the pressure in the accumulator varies between 400 and 650 psi over a complete ram stroke. Since it is not known how accumulator pressure varies with cylinder pressure, it was necessary to use these fixed conditions as valid estimates of the accumulator pressure change. Given these initial conditions, the following equation applies:

$$\text{PACCO X VOLACO}^{1.4} = \text{PACCT X VOLACT}^{1.4}$$

The original pressure and volumes are known, (PACCO and VOLACO), the new volume (VOLACT) can be calculated as a function of ram stroke*, and so the pressure in the accumulator at any time PACCT can be calculated.

$$\text{PACCT} = \frac{\text{PACCO X VOLACO}^{1.4}}{\text{VOLACT}^{1.4}}$$

*The volume in the accumulator varies with the displacement of fluid from the main engine cylinder. Since it is not an exact function, i.e. varies with piston area and ram stroke, it was necessary to interpolate from the known initial and final conditions to determine how this volume varies.

$$\text{VOLACT}^{1.4} = (\text{VOLACO} - (\text{SK X STROKE}))^{1.4}$$

where SK is the calculated dummy variable that best fits the prescribed conditions.

f. Cylinder Pressure. The pressure in the cylinder is the sum of the drop across the orifice and the increase in accumulator pressure.

$$\text{PMEC} = \text{DPMEC} + \text{PACCT}$$

9. FORCES ACTING ON THE SYSTEM.

a. Ram Force. The ram force is the build-up of cylinder pressure acting as a unit vector against the piston area

$$\text{FRAM} = \text{PMEC X AREPTN}$$

b. Cable Tension. The arresting gear cables are wrapped around two crossheads, one fixed and one movable. Each crosshead has two banks of sheaves, an upper and lower. Coming down from the top side connection with the deck pendant and wrapped around some intermediate directional sheaves, each cable is wrapped around either both upper banks of sheaves or both lower banks of sheaves. Thus on the movable crosshead the ram force developed by the pressure buildup is equal and opposite to the tension developed by the wrapped around wires.

FRAM - CBLTEN = 0

Since one individual cable is wrapped around nine rows of sheaves, applying a force to the top and bottom of the sheaves, the total cable tension in reaction to the ram force is now

FRAM -(9 x 2 x CBLTEN)= 0

Since there are two cables, one for each bank, the net result is

FRAM -(9 x 2 x 2 x CBLTEN)= 0

or CBLTEN = FRAM / 36 for the Mark 7 Mod 1 arresting gear with a conventional wrap.

In the above discussion, it was noted that the net force acting in the opposite direction to the ram was the cable tension. There is another force, friction drag, which also acts within the system. This force is to due to cable drag, cable bounce, slipper friction, etc. It is the summation of all the additional force outside of the main engine cylinder that arrest the aircraft.

CBLTEN = FRAM / 36 + FDRAG

FDRAG = (1 - MCHEFF) x TOTENG / 2 x CBLPOU

where TOTENG is the total energy of the engagement.

c. Hookload. Hookload is the force transmitted from the cable to the hook. For on center arrestments it is

HKLOAD = 2 x CBLTEN x COS (θ)

d. Thrust. Engine thrust developed by the aircraft acts in the opposite direction to the retarding forces developed by the arresting engine. A standard method of approximating it is .4 to .65 times the weight of the plane.

THRUST = K x ACWGHT

e. Deceleration. From Newton's Law, F=Ma, the combination of hookload and thrust results in

$$\text{THRUST} - \text{HKLOAD} = \frac{\text{ACWGHT}}{\text{ACGTY}} \times \text{DECEL}$$

DECEL = rate of change of aircraft velocity. Since the engaging velocity is known, it is possible, through the computer program, and assuming a constant aircraft acceleration during each time step, to calculate the new velocity at the end of the time increment. That is

$$\text{DECEL} = \frac{\text{VELIN} - \text{VELOF}}{\text{TIME}}$$

and $\text{VELOF} = \text{VELIN} + \frac{\text{ACGTY}}{\text{ACWGHT}} (\text{THRUST} - \text{HKLOAD})$

10. MECHANICAL EFFICIENCY. Mechanical efficiency is defined as the energy absorbed by the main engine cylinder taken as a percentage of the total energy of the arrestment. Since previous experimental calculations of mechanical efficiency neglected aircraft thrust, it was necessary to make theoretical approximations using the computer program as to its actual value. The equation developed from these approximations is similar to the experimental result obtained from the Mark 7 Mod 3 gear, and in fact, was effective in producing suitable hydraulic pressure cards for the Mark 7 Mod 1.

$$\text{MCHEFF} = .201\ (\text{TOTENG})^{.084}$$

11. VELOCITY COEFFICIENT. The velocity coefficient is a measure of the viscous losses during contraction of the fluid. Actual velocity coefficients for any type orifice can be only determined experimentally. It was necessary, therefore, to apply the same theoretical procedure for approximating velocity coefficients as with mechanical efficiency. The range of velocity coefficients was known. For different weights and speeds, different coefficients were substituted until suitable hydraulic cards were developed. For the sake of simplicity in the computer program, an equation for velocity coefficients was developed as a function of aircraft weight.

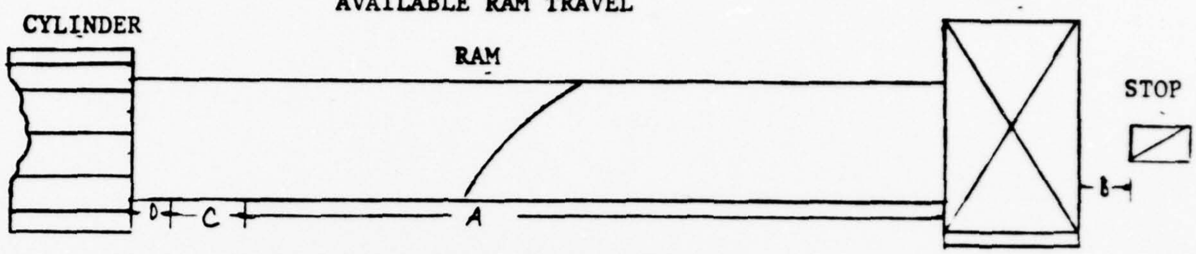
$$\text{VELCOF} = 3.126\ \text{X}\ (\text{ACWGHT})^{-.111}$$

12. DESIGN CONDITIONS.

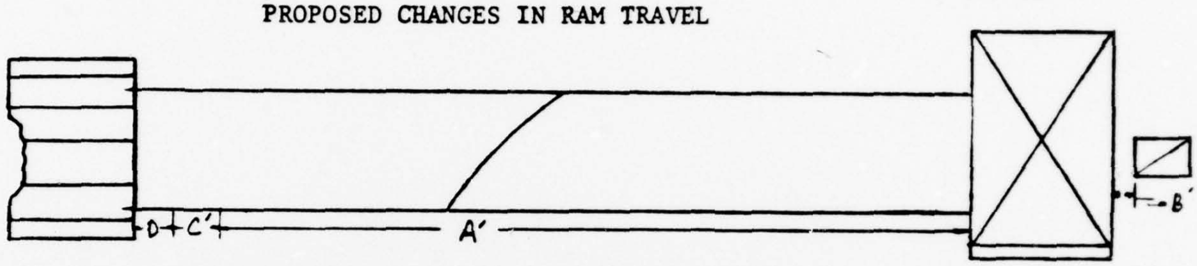
a. Hydraulic Ram Stroke.

(1) The following diagrams compare the present operating conditions with the proposed changes.

MARK 7 MOD 1 ARRESTING GEAR
AVAILABLE RAM TRAVEL



PROPOSED CHANGES IN RAM TRAVEL



	Present Conditions	Proposed Conditions
A - Total Ram Travel	118"	
A' - Total Ram Travel		122"
B - Initial Crosshead Location	9"	
B' - Initial Crosshead Location		7"
C - Two-Block Safety Distance	4 5/8"	
C' - Two-Block Safety Distance		2 5/8"
D - Two-Block Stopper	2 1/4"	2 1/4"
E - Length of Two-Block Stroke	133 7/8"	133 7/8"

The reduction of the two-block distance from 4 5/8" to 2 5/8" and the placement of the crosshead at the 7" mark, allows for a total ram travel of 122". As the cable stretches, and the crosshead moves towards the crosshead stop, additional ram travel can be utilized by further rotation of the cam.

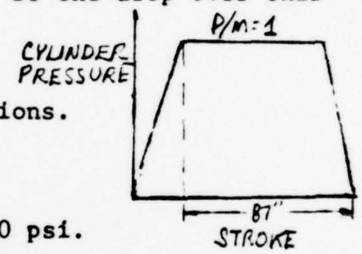
b. Mean Cylinder Pressure Drop

Maximum Cylinder Pressure - 10,000 psi
Present Ram Travel - 118.1 inches
Proposed Ram Travel - 122.0 inches
Piston Area - 314.16 sq. in.
Total Energy Absorbed = 10,000 psi x $\frac{118.1}{12}$ in. x 314.16 sq. in.

= 30.9 x 10^6 ft-lbs.
Mean Cylinder Pressure Drop =
$(10{,}000 - dp) \times \frac{122}{12} \times 314.16 = 30.9 \times 10^6$ ft-lbs.

dp = 320 psi

The Mean Cylinder Pressure range is 87 inches. So the drop over this range is $\frac{122}{87} \times 320 = 450$ psi.

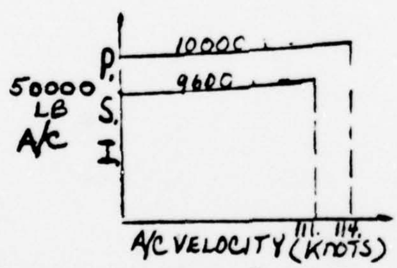


Assuming an 85% efficiency after maximum conditions.

.85 x 450 = 380 psi

For 122" ram travel, the design condition is 400 psi.

c. New Engaging Velocity. From NAEC MISC 09344, a 50,000 lb. aircraft @ 111 knots, develops a 10,000 psi MEC pressure. The 400 psi drop due to the extended ram travel corresponds to a velocity change of 3 knots. The new engaging velocity is now theoretically 114 knots.



d. New Dial Curve. An aircraft dial curve has been developed for the 122" ram stroke. (See Figure 25). The effect of the new cam coordinates on a wide range of pressure cards is shown in Figures 26-29.

IV. RESULTS AND DISCUSSION

The reliability of the MK 7 Mod 1 hydraulic simulation program was established by pressure simulations of actual aircraft test events. The experimental and theoretical plots showed similar trends. (See Figures 1-8).

The aircraft weight dial settings used in the simulation were from the actual test settings. Velocity coefficients and mechanical efficiency values (See Figure 10) were taken from the theoretical equations derived specifically for the Mod 1 gear. The thrust ratings used in the A-3 performance simulations and the development of the aircraft weight settings were .4 times the weight of the aircraft. In the development of simulations for 118.1 inch stroke, the thrust ratings varied according to projected aircraft capability. (This was necessary because over an extended runout a variance of .1 to .2 percentage points for the K factor results in a significant total energy difference).

The main engine cylinder pressure limit of the Mod 1 is 10,000 psi. Aircraft calibration test reports for the Mod 1 gear show that a 50,000 lb. aircraft at 111 knots will develop this peak cylinder pressure. (The A-3 was used because it is the heaviest in the fleet. The F-4J also develops critical loads because of its specific aircraft requirements). Figure 9 shows the simulation of this condition.

Figures 11 and 12 are comparison plots of the pressure trends for the 122" cam designs and the 118" K-5 cam. The simulations were made for the A-3 aircraft at various engaging speeds. (See Figures 13-24). The trends meet the 400 psi design criteria throughout the range of engaging velocities.

Figure 25 shows the aircraft dial settings for the extended stroke and the K-5 cam. Figures 26-29 show the development of the dial settings for the new cam design.

The F-4J is a 38,000 lb. plane with an afterburner thrust to weight ratio of .63. Figure 30 shows the cylinder pressures developed in the F-4 using the standard .4 ratio. Figures 31 and 32 show pressure simulations for an F-4J under its landing conditions.

The hydraulic cards for the F-4J show underset conditons. The MEC pressure limit is not exceeded, but the limits for cable tension and hookload are with the afterburner thrust ratings. (See Figures 33-36).

V. CONCLUSIONS

1. The new cam design and the standard K-5 cam rotated on its dwell develop significant pressure reductions in MK 7 Mod 1 arresting gear recovery operations.

2. Peak cable tensions and hookloads should also be reduced with the extended ram stroke, but in order to determine this a more detailed dynamic analysis of the Mod 1 system is necessary.

3. NATF Report R-172 verifies the trends of this study.

4. A rotated cam or a new cam design shows the same theoretical performance of the MK 7 Mod 1 Arresting Gear.

5. The MK 7 program can adequately simulate the hydraulic loads in an aircraft operation.

VI. RECOMMENDATIONS

1. Establish 122" as the operating service stroke for the Mark 7 Mod 1 Arresting Gear with an upper balanced control valve and with a new reeve of purchase cable.

2. Achieve the increased service stroke (from the present 118 inches to 122 inches) by rotation of the existing control valve cam, P/N 502715-1P.

VII. REFERENCES

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(b) NAEF MISC. 07262 - Geometrical and Effective Flow Area vs. Stem Lift: Mark 7 Mod 2-3 Arresting Gear Control Valve

(c) NAEC MISC. 09335 - Mark 7 Mod 1 Arresting Gear Hydraulic Performance Charts

(d) NAEC-ENG-7511 - Performance Analysis of Mark 7 Mod 3 Recovery System Based on Aircraft Calibration Tests by J. Zurzolo

(e) Aircraft Recovery Equipment Handbook - Mark 7 Mod 1, 2, and 3, NAVAIR Publications 51-5BAA-1, 51-5BBA-1, 51-5BCA-1

(f) NATF Report R-172; Evaluation of Mark 7 Arresting Gear Service Changes No. 307 and 320 with the RALS Mark 7 Mod 1 Arresting Gear

CYLINDER PRESSURE VS. RAM STROKE SIMULATION
EVENT 36579
MARK 7 MOD 1 ARRESTING GEAR
K-5 CAM-118.1" STROKE
A-4 A/C WEIGHT-13900 LBS.
ENGAGING VELOCITY-100.0 KNOTS

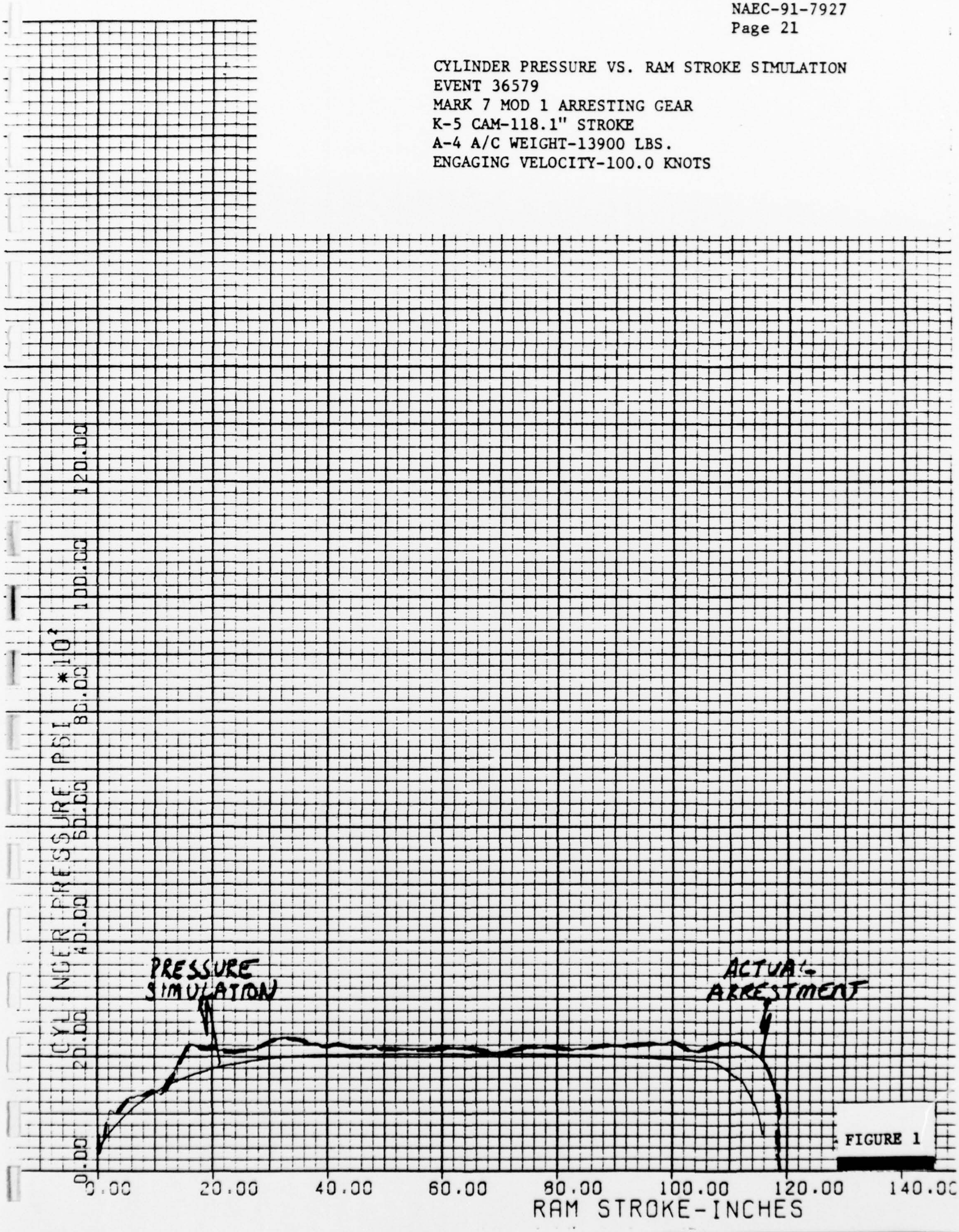


FIGURE 1

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
EVENT 36589
MARK 7 MOD I ARRESTING GEAR
K-5 CAM-118.1" STROKE
A-4 A/C WEIGHT 14000 LBS.
ENGAGING VELOCITY-113.4 KNOTS

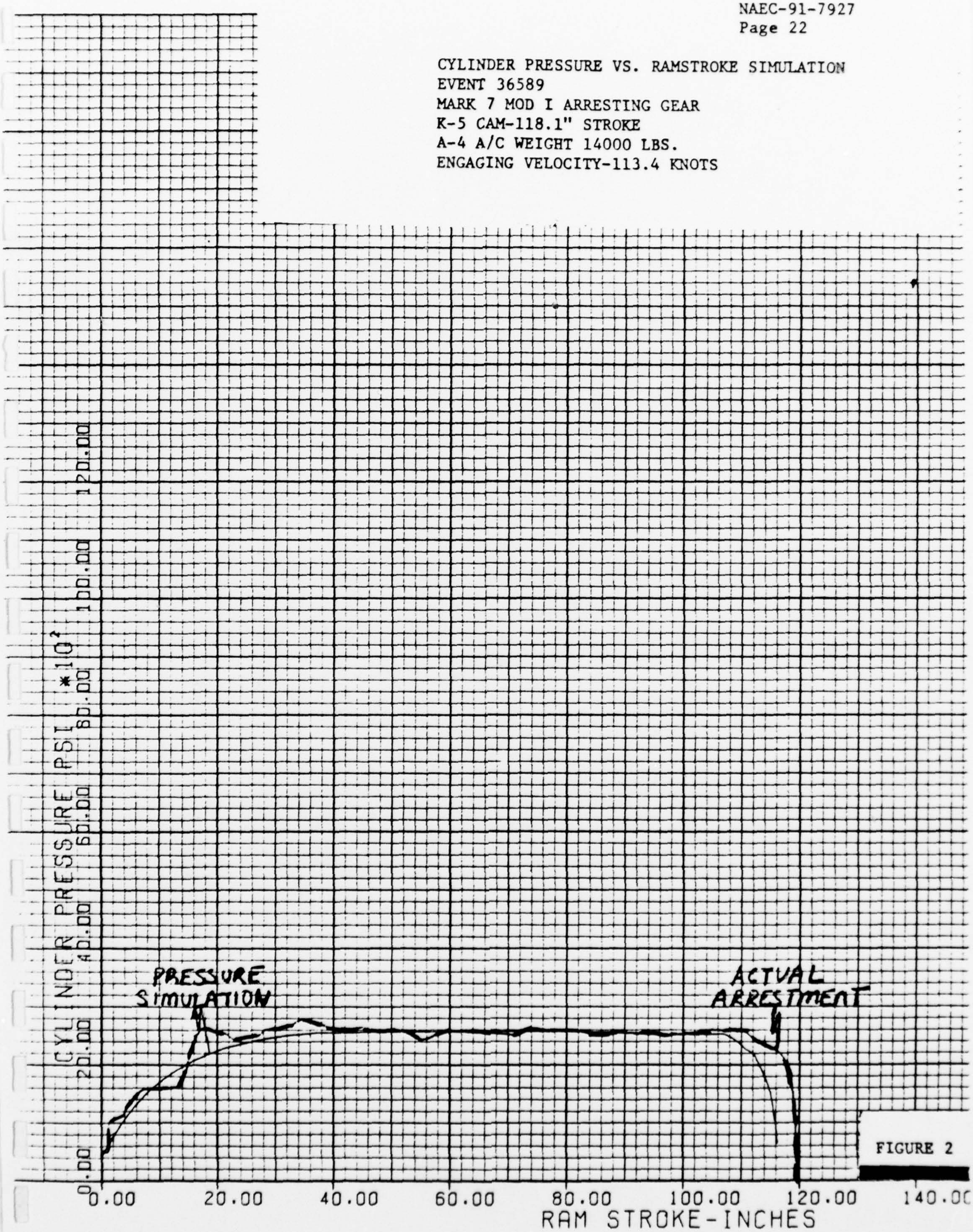


FIGURE 2

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
EVENT 36574
MARK 7 MOD I ARRESTING GEAR
K-5 CAM-118.1" STROKE
A-7 A/C WEIGHT 25200 LBS.
ENGAGING VELOCITY-110.4 KNOTS

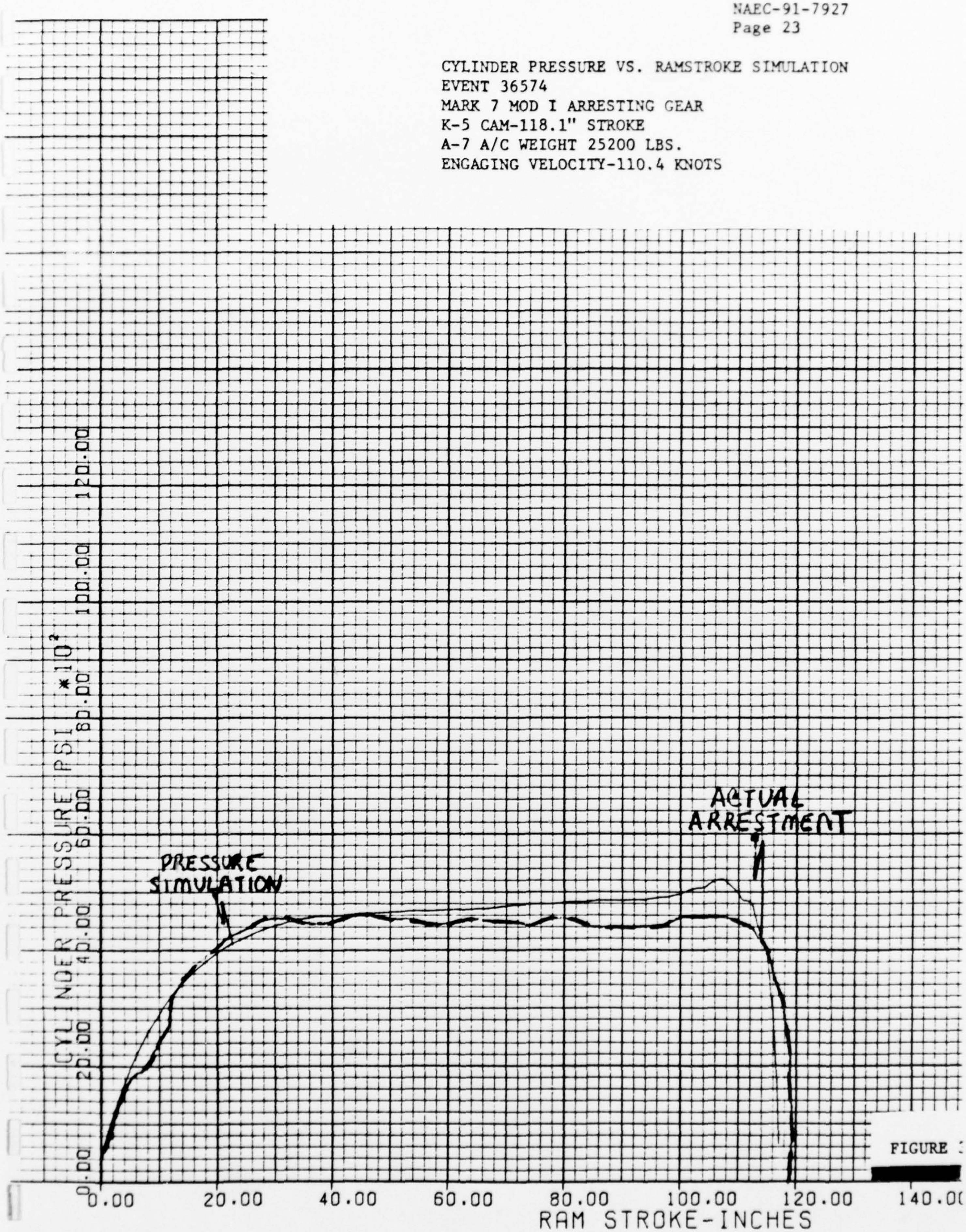


FIGURE :

CYLINDER PRESSURE VS. RAM STROKE SIMULATION
EVENT 36575
MARK 7 MOD I ARRESTING GEAR
K-5 CAM-118.1" STROKE
A-7 A/C WEIGHT 25100 LBS.
ENGAGING VELOCITY-105. KNOTS

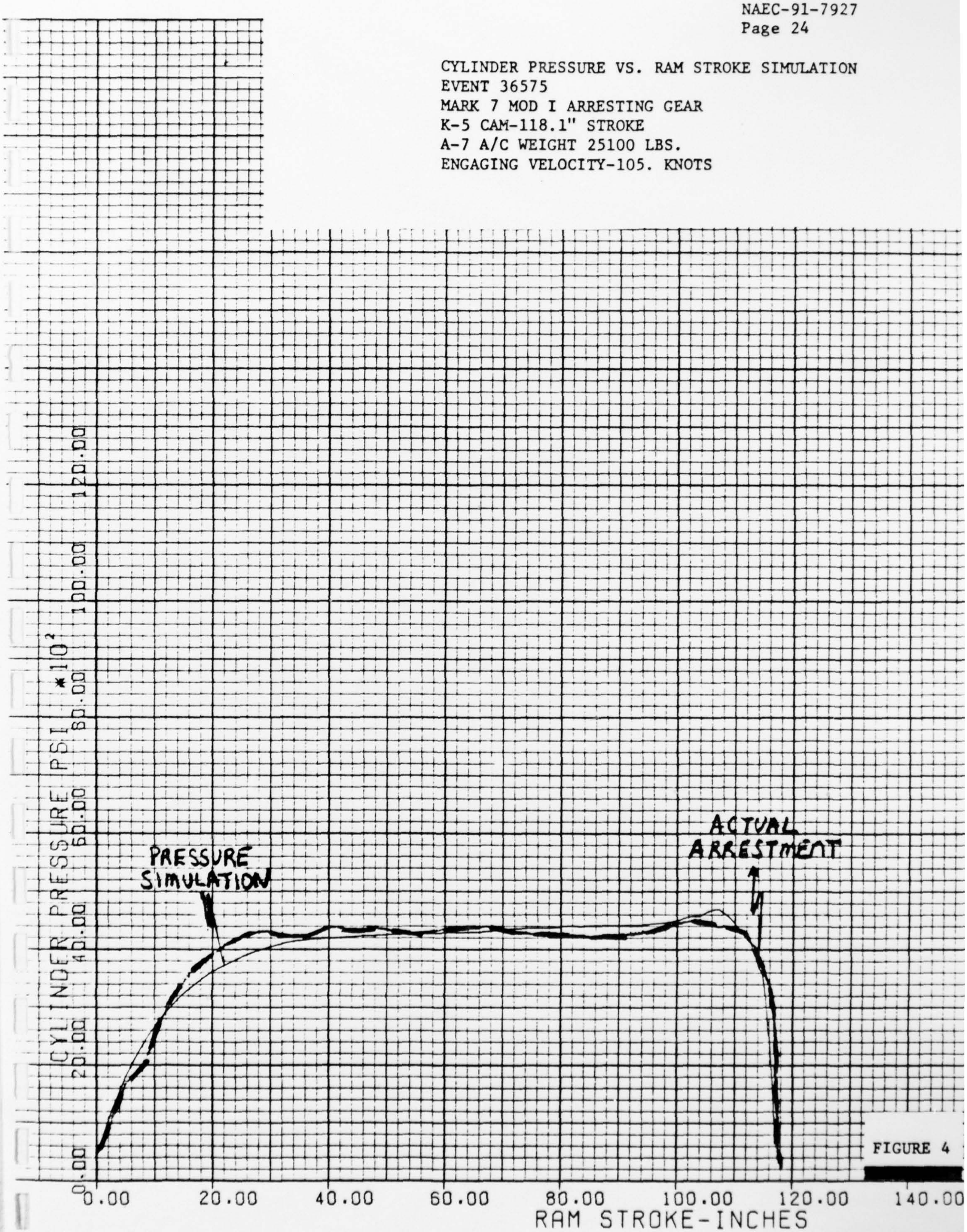


FIGURE 4

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
EVENT 36667
MARK 7 MOD I ARRESTING GEAR
K-5 CAM-118.1" STROKE
F-4J A/C WEIGHT 37200 LBS.
ENGAGING VELOCITY-93.0 KNOTS

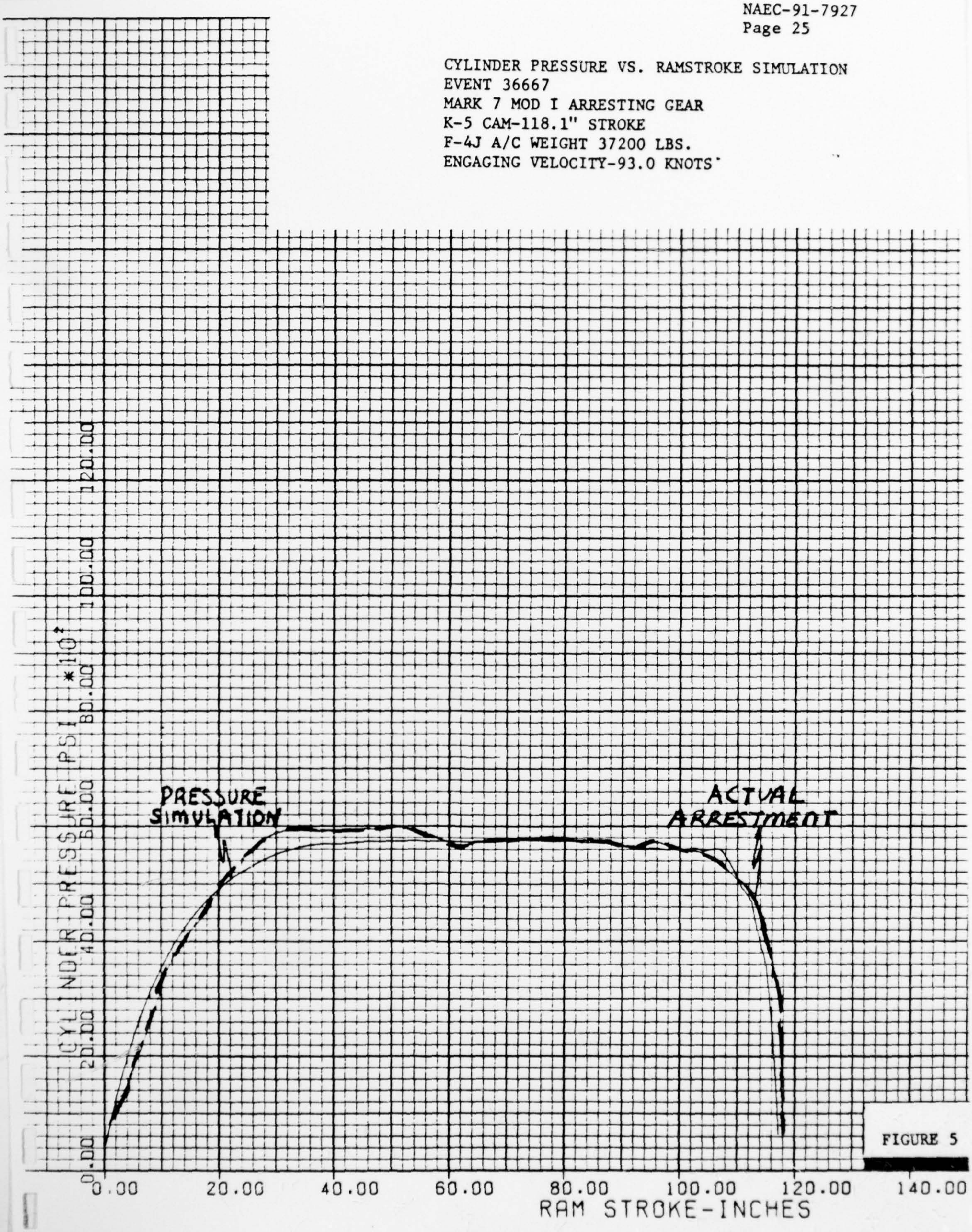


FIGURE 5

CYLINDER PRESSURE VS. RAM STROKE SIMULATION
EVENT 36668
MARK 7 MOD I ARRESTING GEAR
K-5 CAM 118.1" STROKE
F-4J A/C WEIGHT 36800 LBS.
ENGAGING VELOCITY-108.9 KNOTS

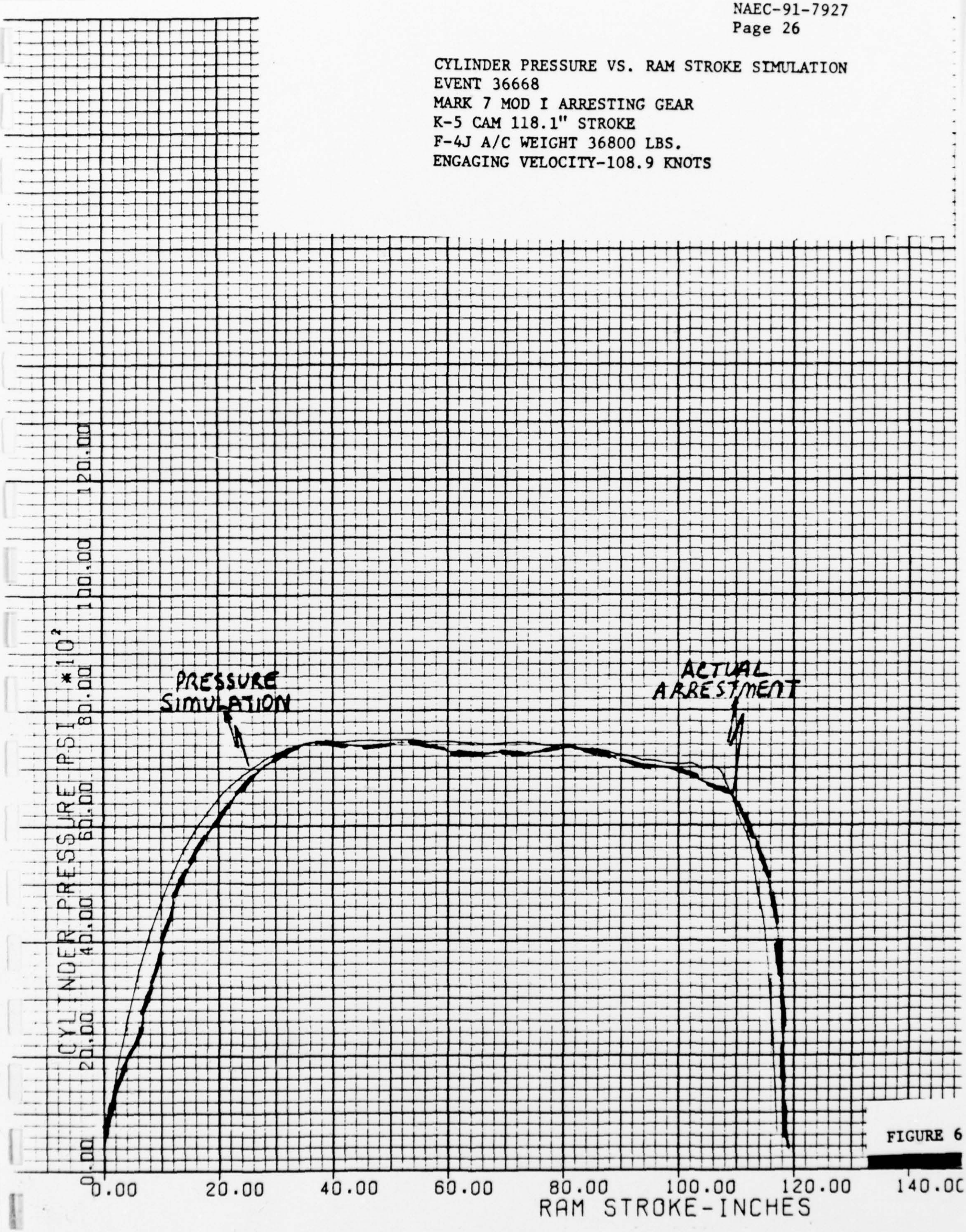


FIGURE 6

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
EVENT 36644
MARK 7 MOD I ARRESTING GEAR
K-5 CAM-118.1" STROKE
A-3 A/C WEIGHT 49200 LBS.
ENGAGING VELOCITY-90 KNOTS

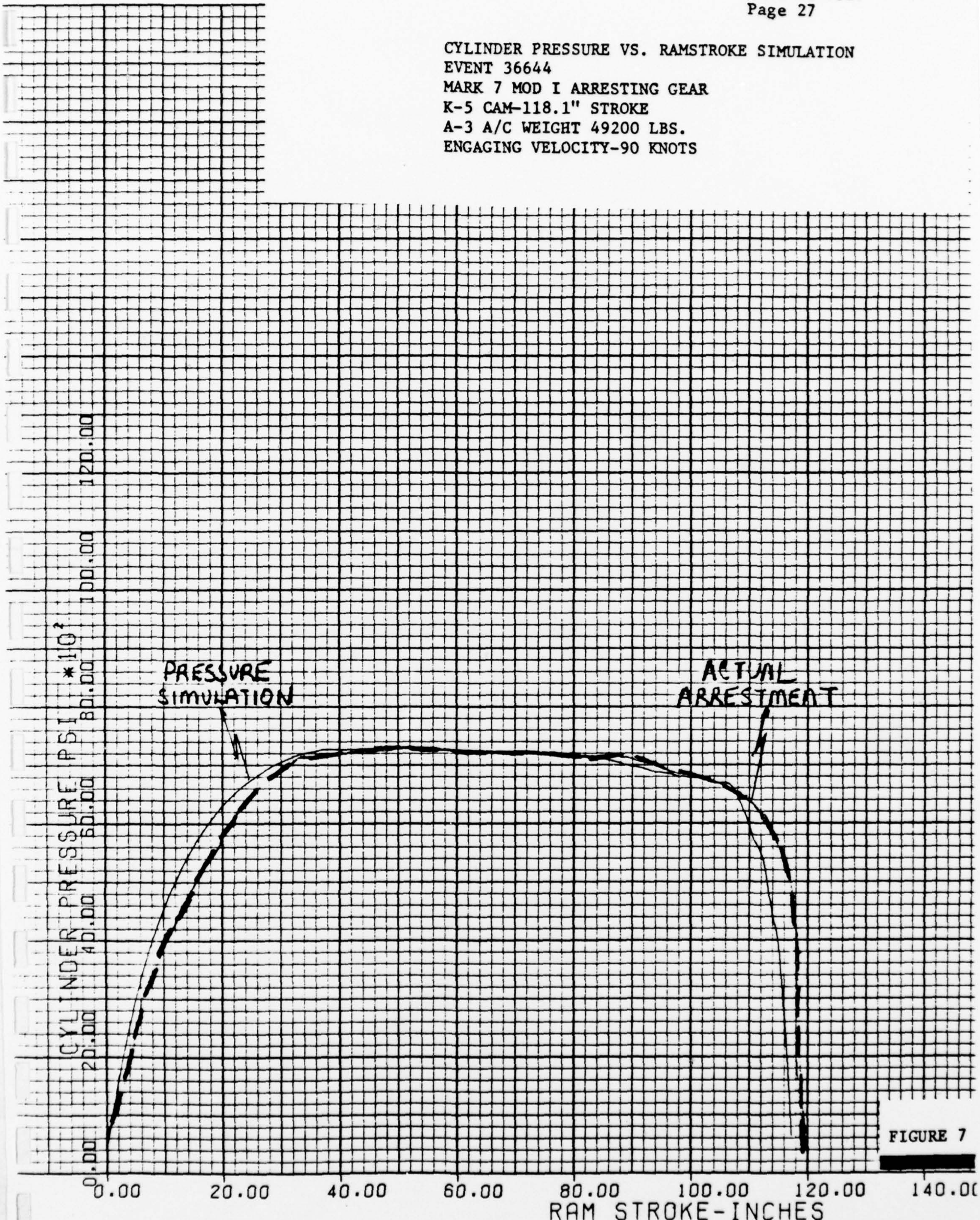


FIGURE 7

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
EVENT 36649
MARK 7 MOD I ARRESTING GEAR
K-5 CAM-118.1" STROKE
A-3 A/C WEIGHT 49500 LBS.
ENGAGING VELOCITY-105.4 KNOTS

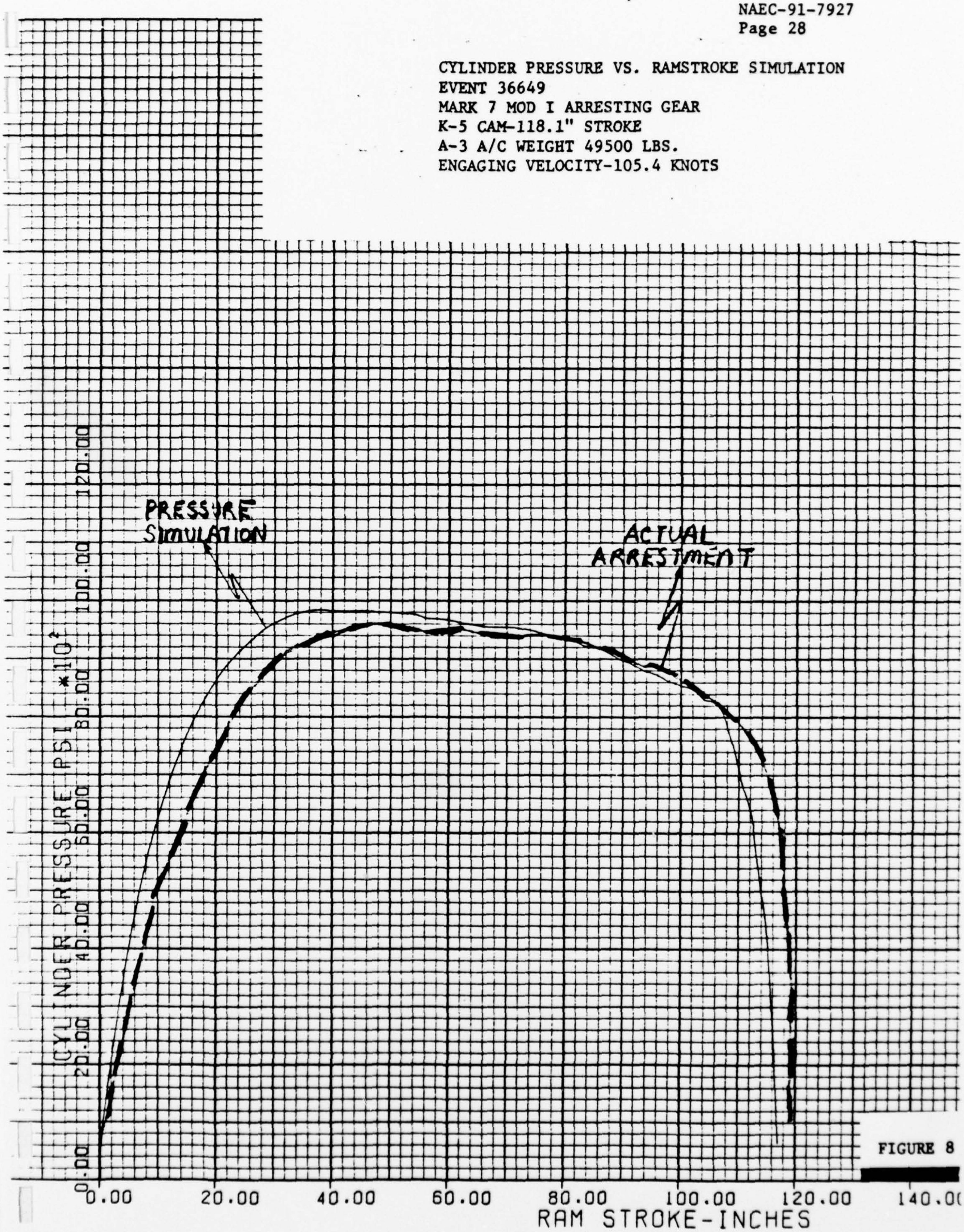


FIGURE 8

CYLINDER PRESSURE VS. RAM STROKE SIMULATION
MARK 7 MOD I ARRESTING GEAR
K-5 CAM-118.1" RAMSTROKE
A-3 A/C WEIGHT 50000 LBS.
ENGAGING VELOCITY-111.0 KNOTS
DIAL SETTING-3.16

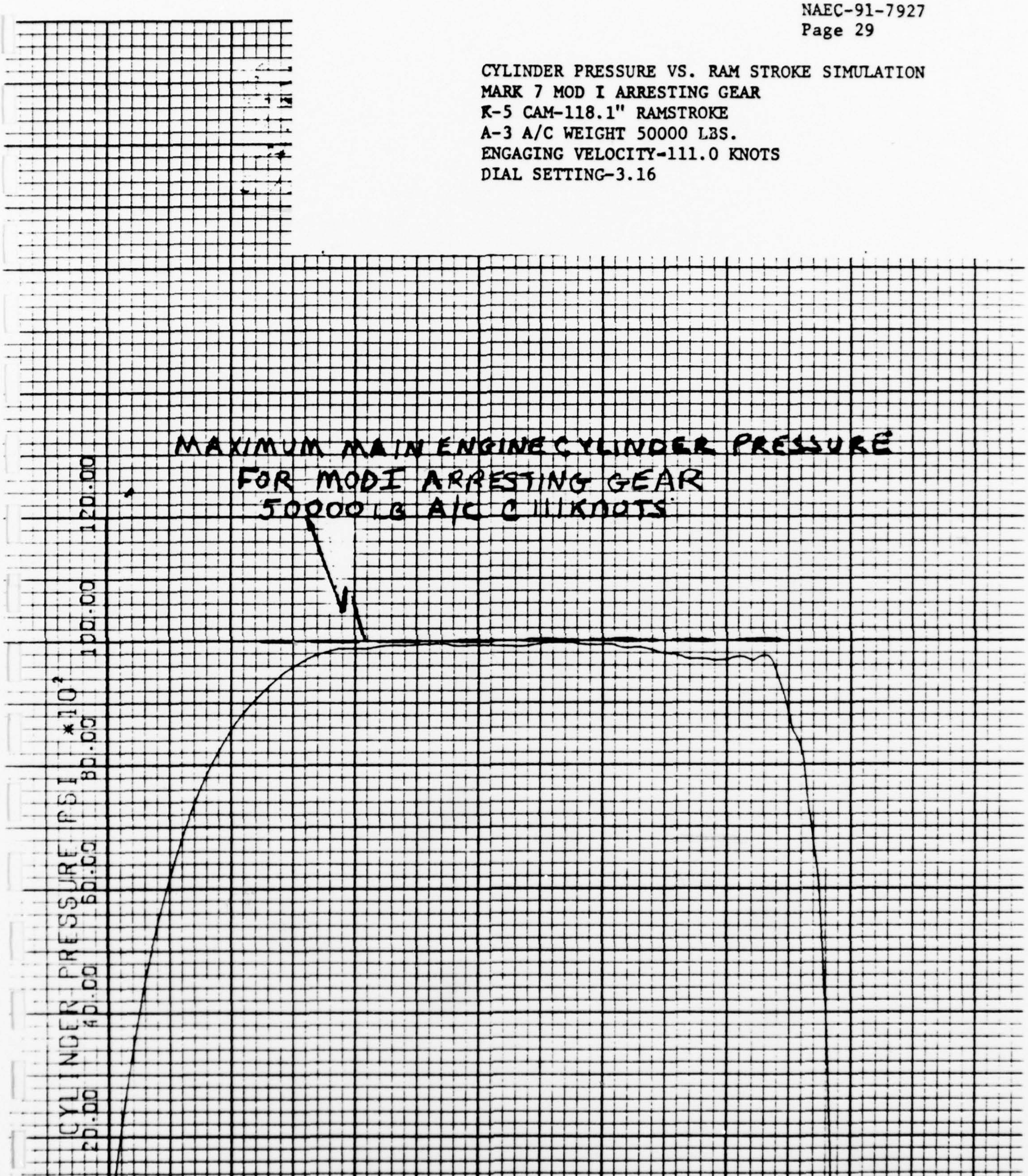
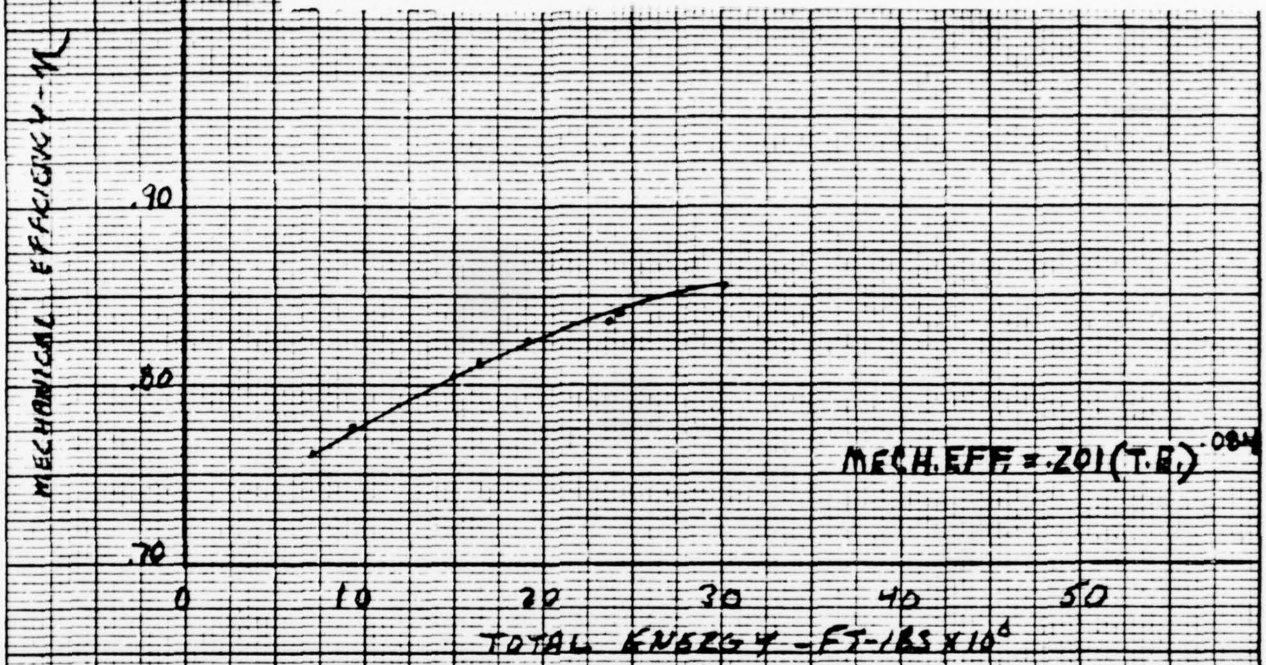


FIGURE 9

MARK 7 MOD I ARRESTING GEAR
MECHANICAL EFFICIENCY VS. TOTAL ENERGY



MARK 7 MOD I ARRESTING GEAR
VELOCITY COEFFICIENT VS. AIRCRAFT WEIGHT

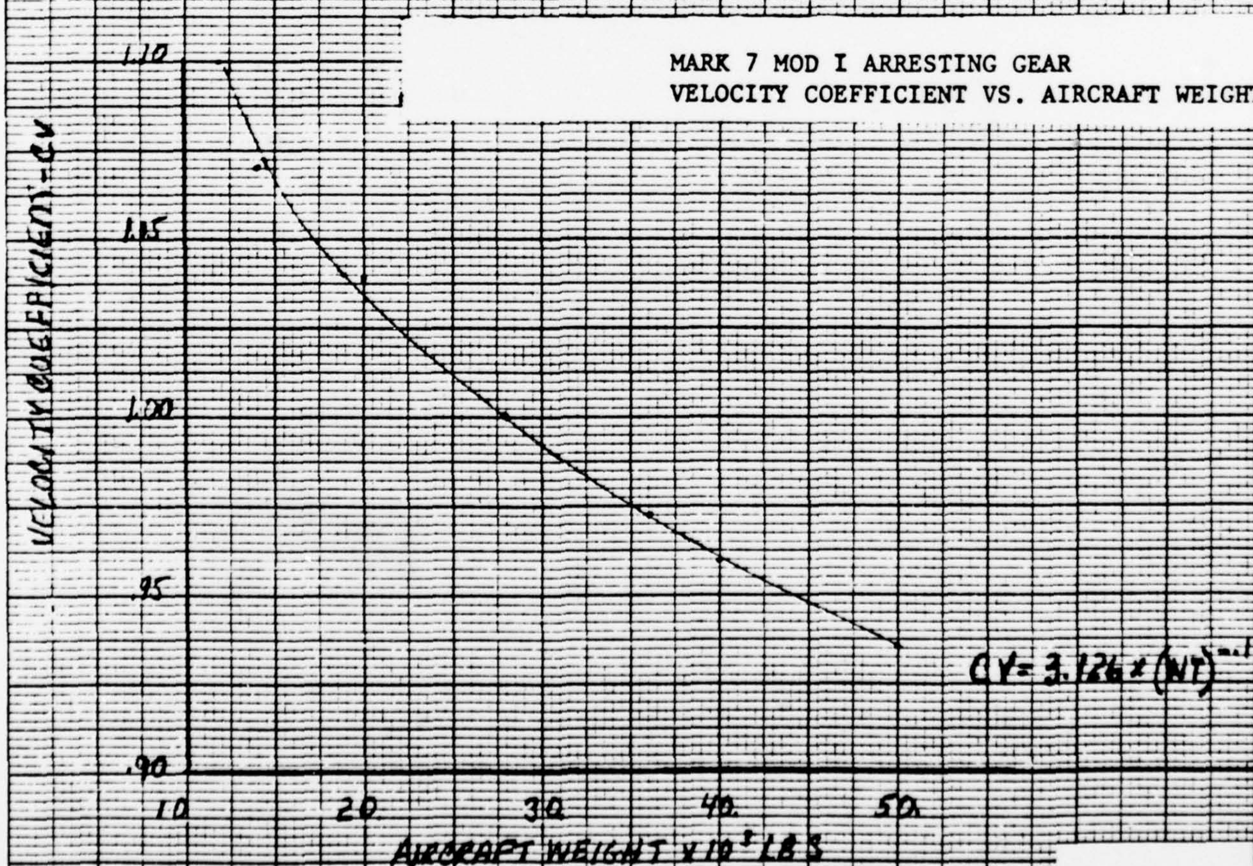


FIGURE 10

MARK 7 MOD 1 ARRESTING GEAR
PEAK CYLINDER PRESSURE VS. ENGAGING VELOCITY
COMPARATIVE PERFORMANCE PLOTS
A-3 AIRCRAFT

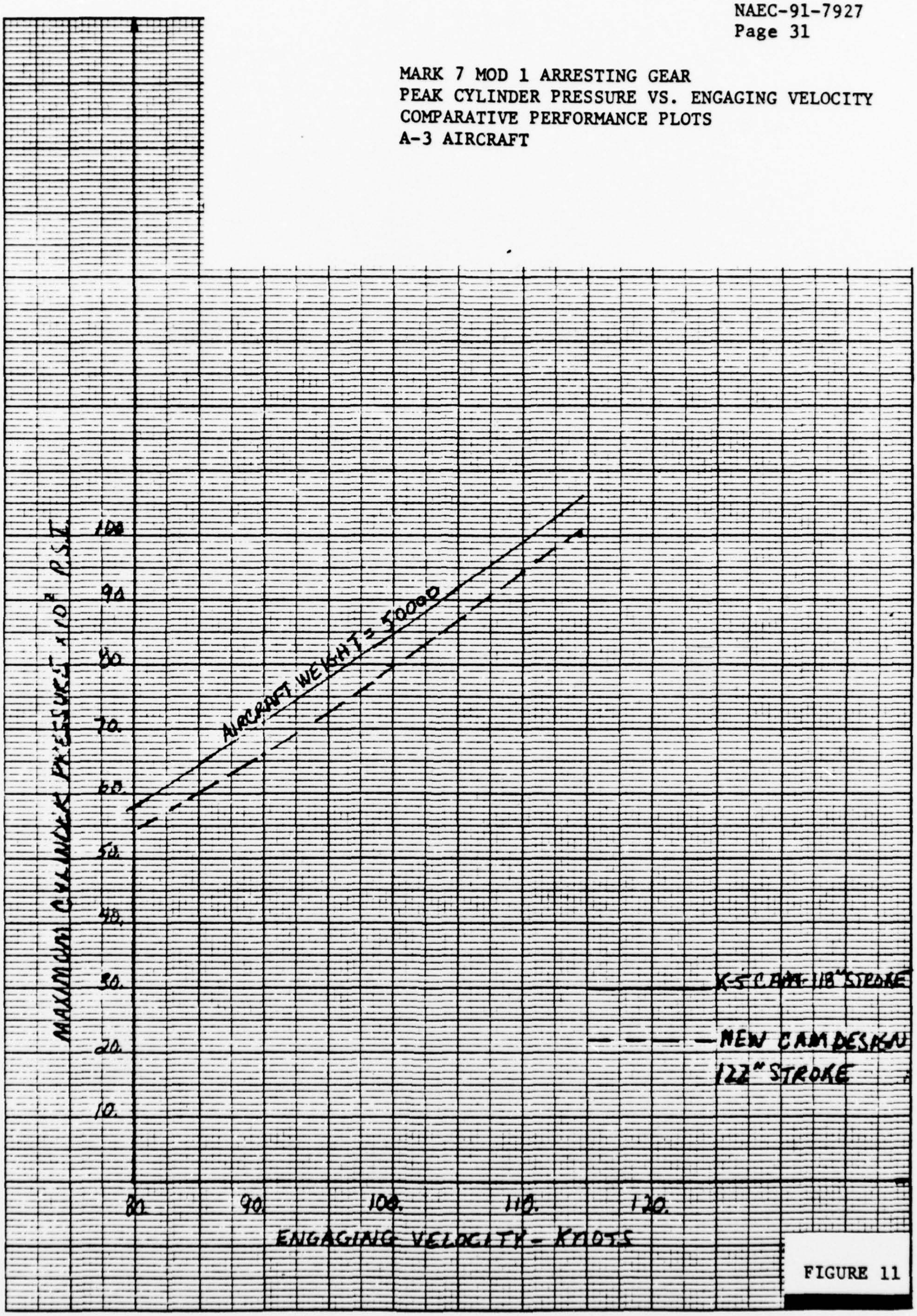


FIGURE 11

MARK 7 MOD 1 ARRESTING GEAR
PEAK CYLINDER PRESSURE VS. ENGAGING VELOCITY
COMPARATIVE PERFORMANCE PLOTS
A-3 AIRCRAFT

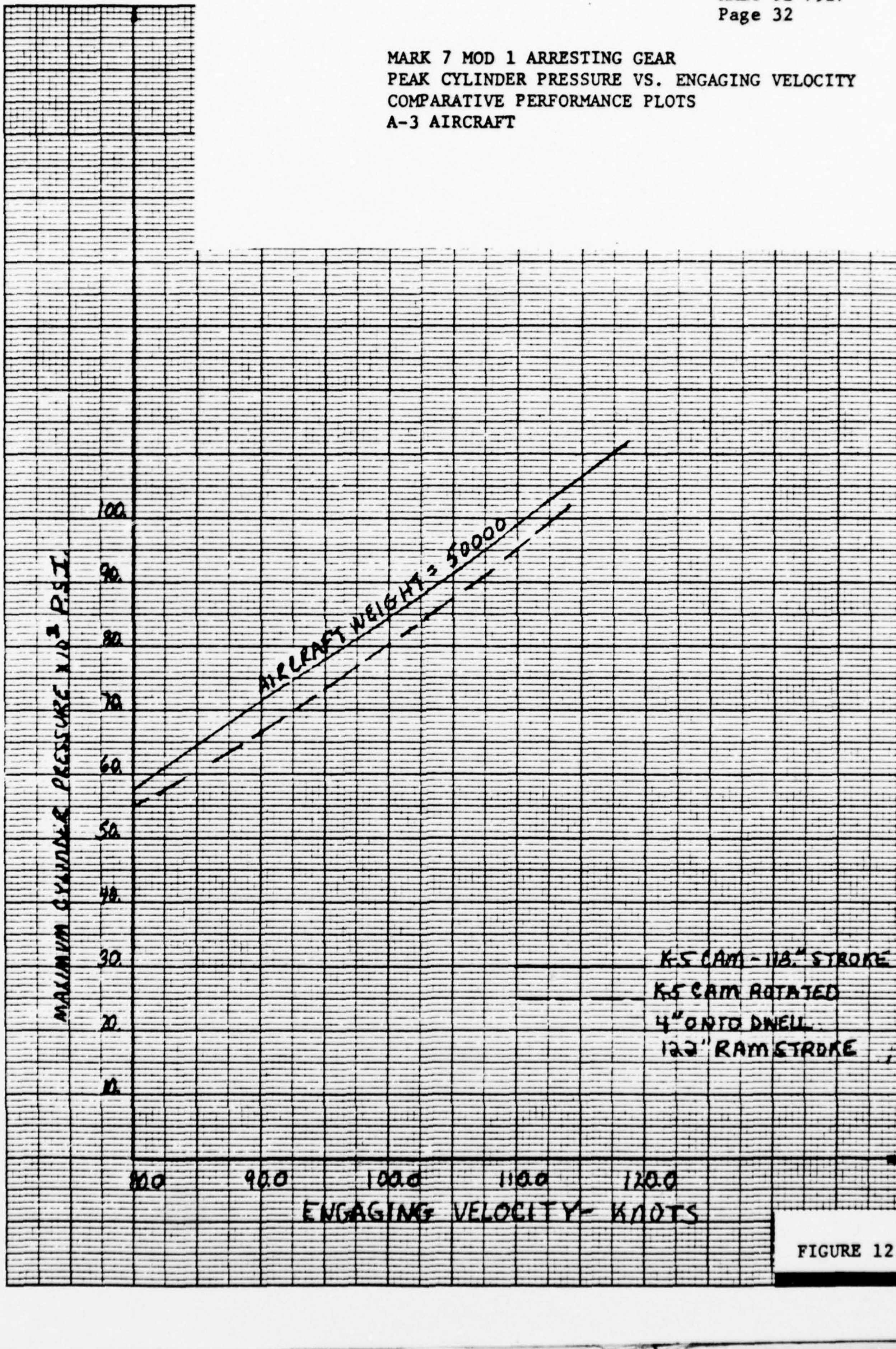


FIGURE 12

CYLINDER PRESSURE VS. RAM STROKES SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
A-3 A/C WEIGHT 50000 LBS.
ENGAGING VELOCITY-80 KNOTS
DIAL SETTINGS-3.3

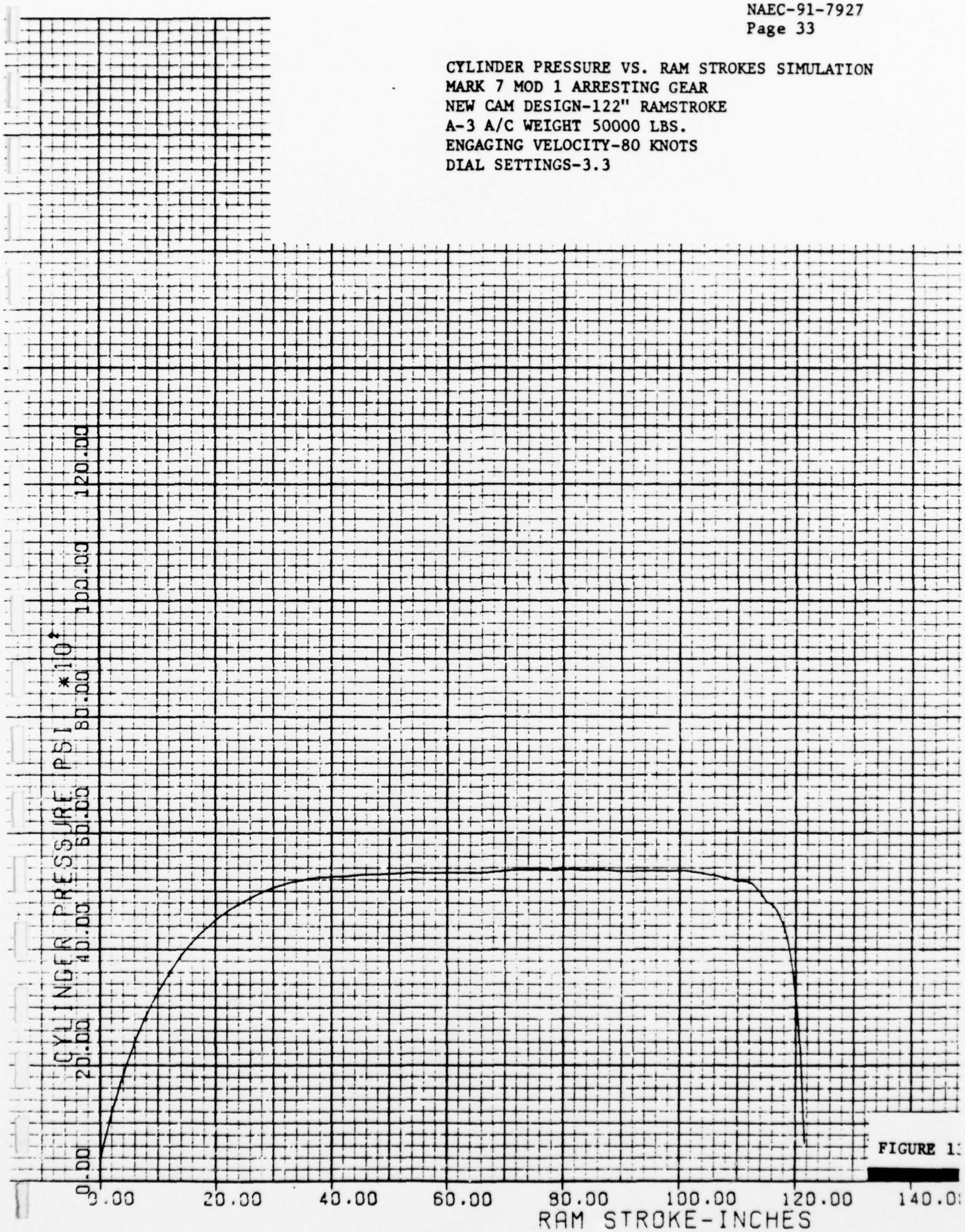


FIGURE 1

CYLINDER PRESSURE VS. RAM STROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
A-3 A/C WEIGHT-50000 LBS.
ENGAGING VELOCITY-90.0 KNOTS
DIAL SETTING-3.3

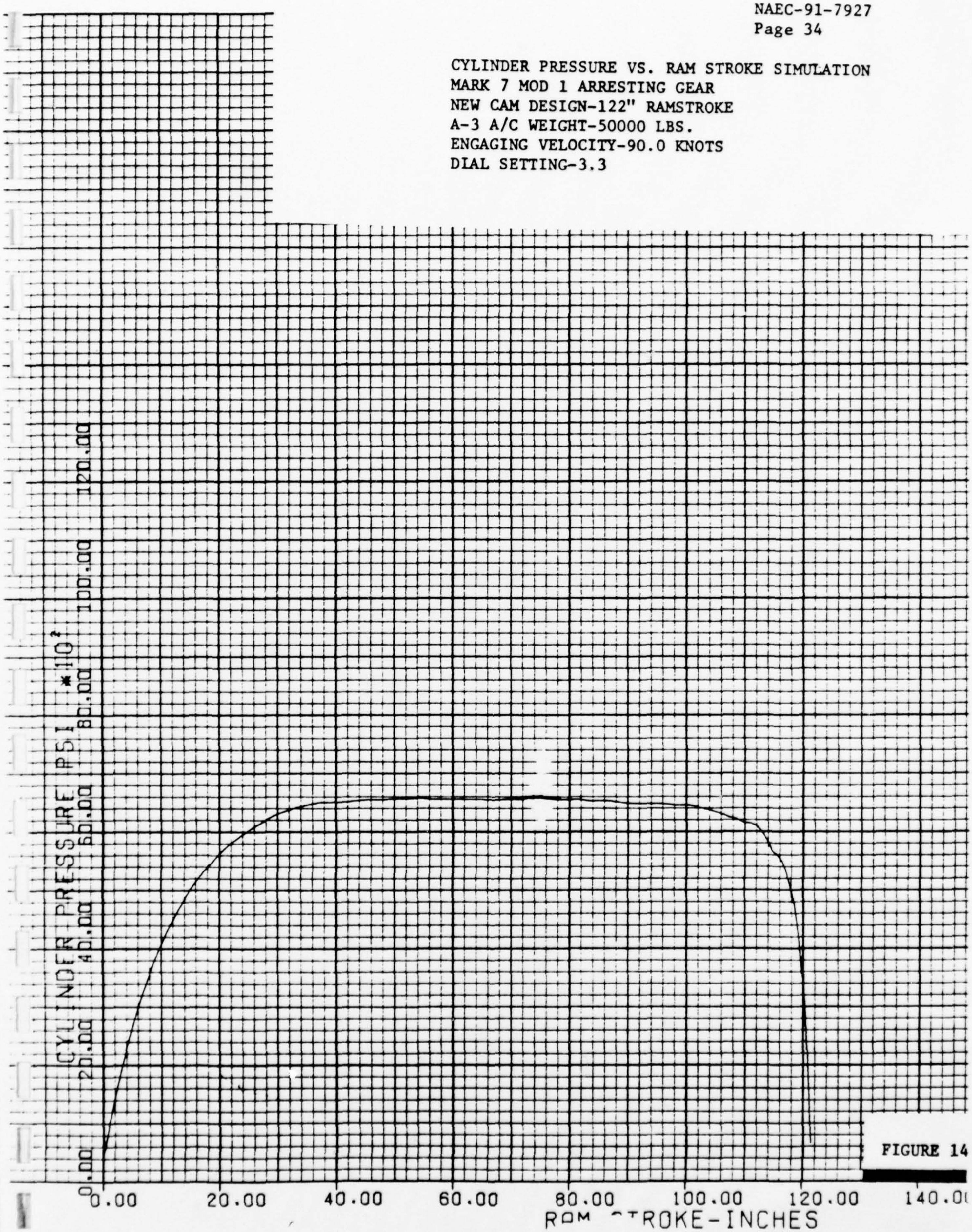


FIGURE 14

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
A-3 A/C WEIGHT-50000 LBS.
ENGAGING VELOCITY-100 KNOTS
DIAL SETTING-3.3

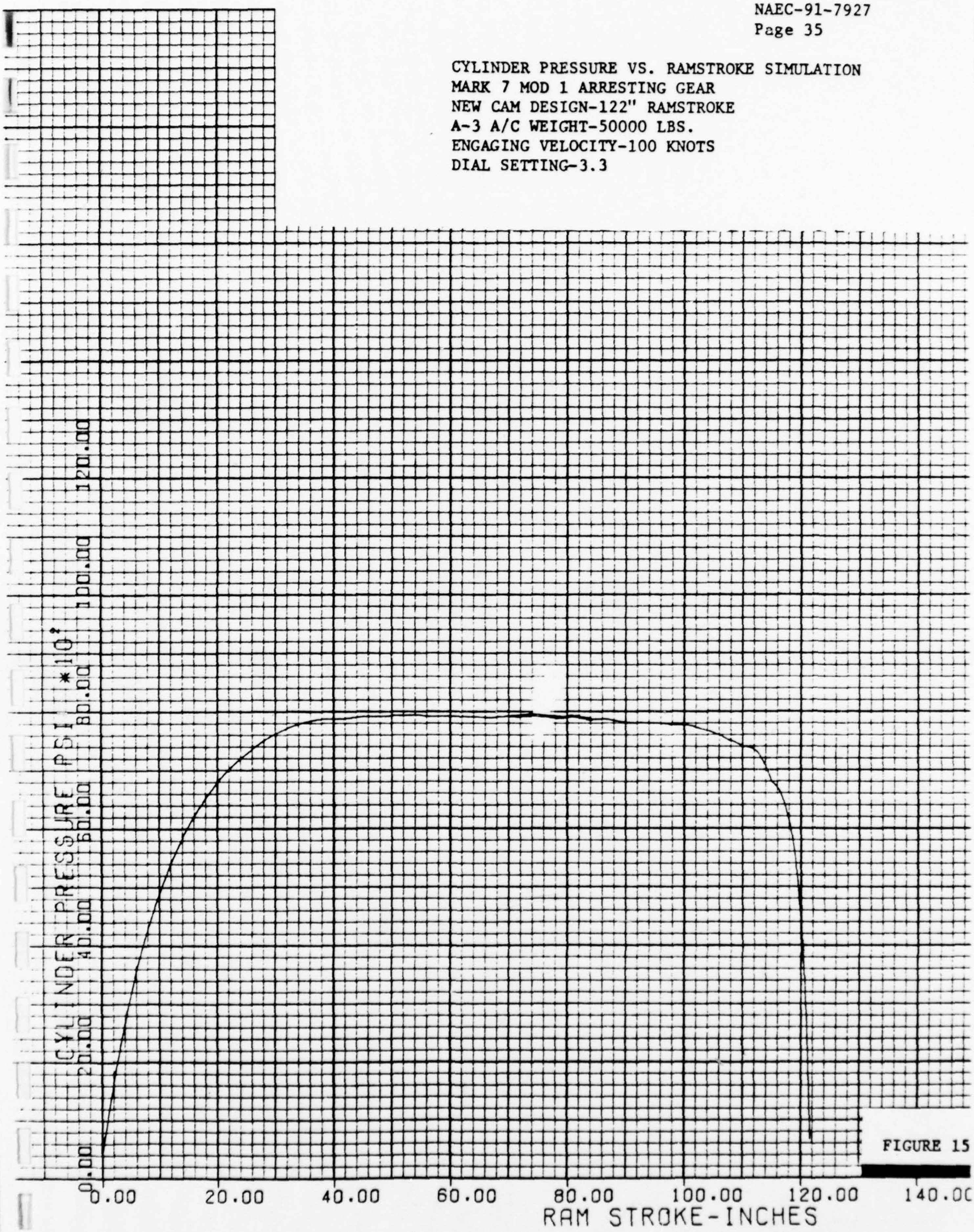


FIGURE 15

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
A-3 A/C WEIGHT-50000 LBS.
ENGAGING VELOCITY-110.0 KNOTS
DIAL SETTING-3.3

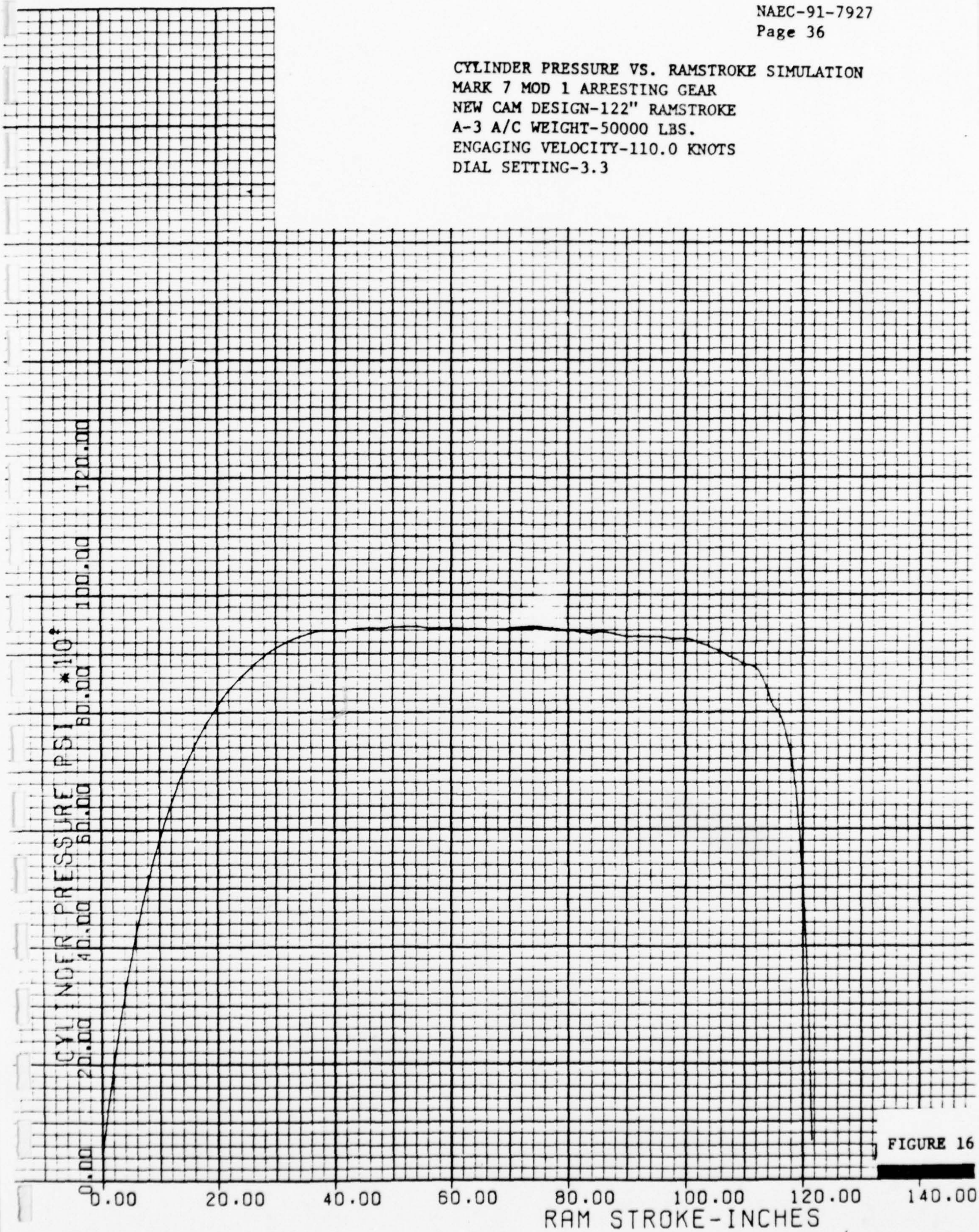


FIGURE 16

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
A-3 A/C WEIGHT-50000 LBS.
ENGAGING VELOCITY-111.0 KNOTS
DIAL SETTING-3.3

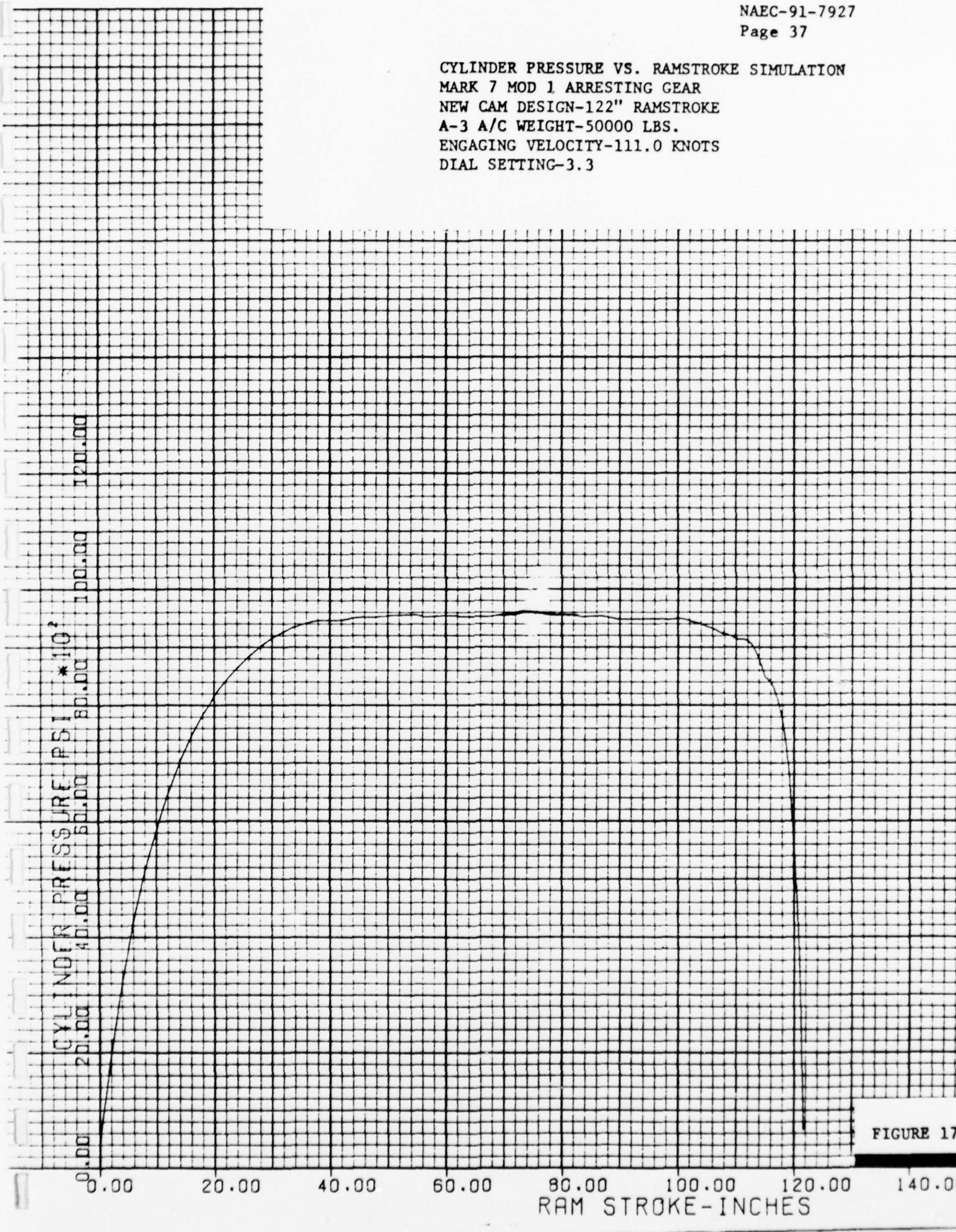


FIGURE 17

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
A-3 A/C WEIGHT-50000 LBS.
ENGAGING VELOCITY-114.0 KNOTS
DIAL SETTING-3.3

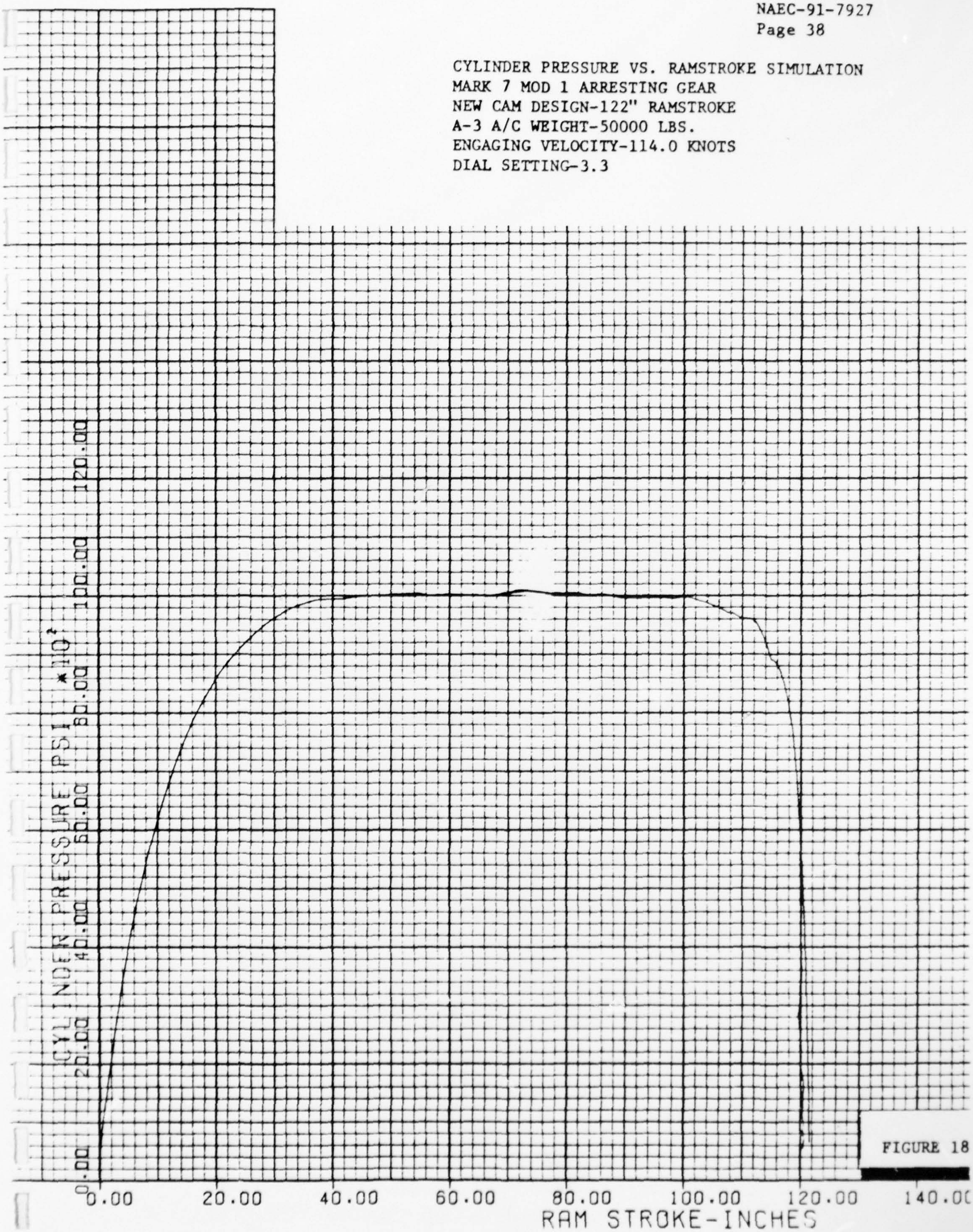


FIGURE 18

CYLINDER PRESSURE VS. RAM STROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
K-5 CAM ROTATED 4" ONTO DWELL-122" RAMSTROKE
A-3 A/C WEIGHT-50000 LBS.
ENGAGING VELOCITY-80.0 KNOTS
DIAL SETTING-3.16

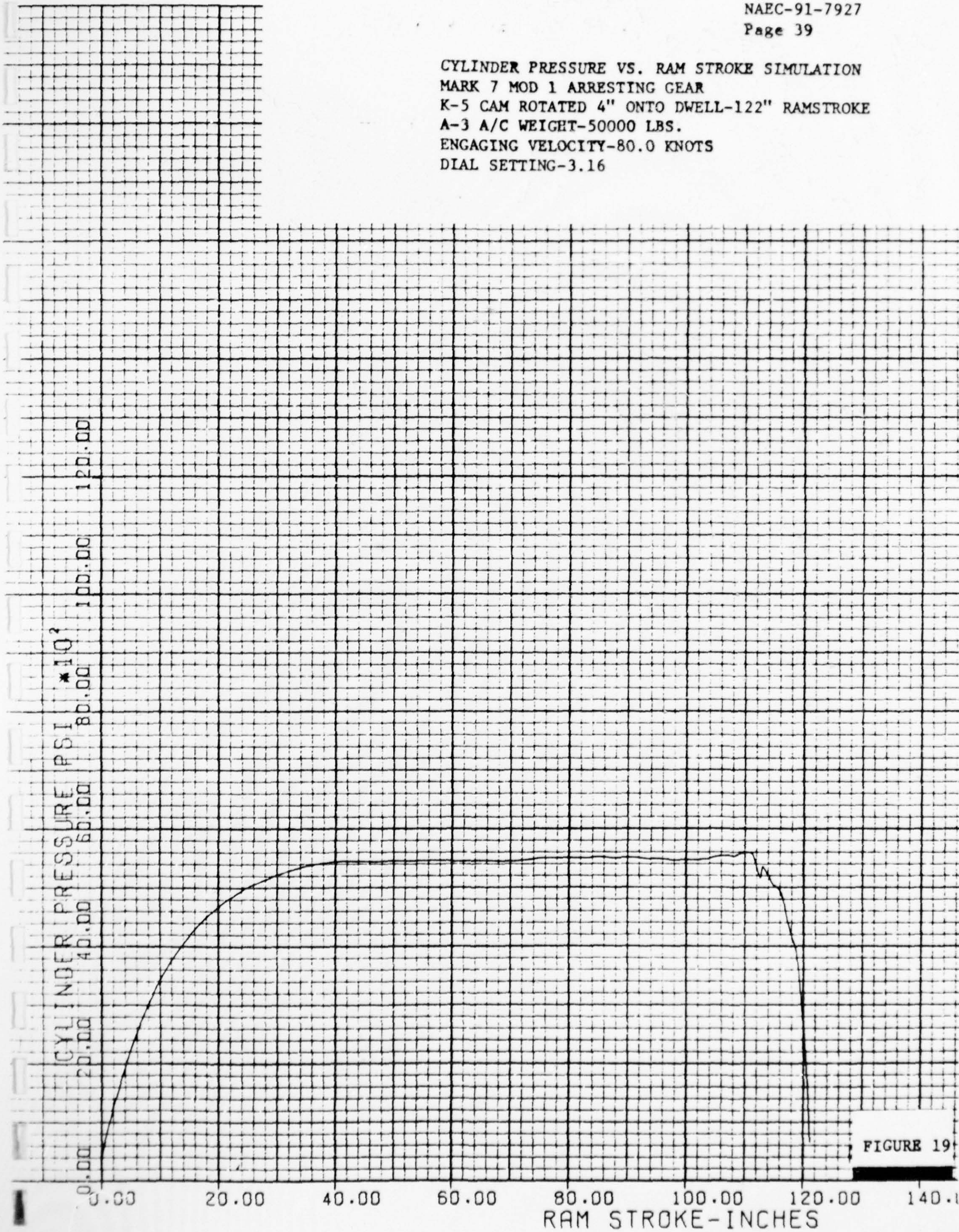


FIGURE 19

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
K-5 CAM ROTATED 4" ONTO DWELL-122" RAMSTROKE
A-3 A/C WEIGHT-50000 LBS.
ENGAGING VELOCITY-90.0 KNOTS
DIAL SETTING-3.16

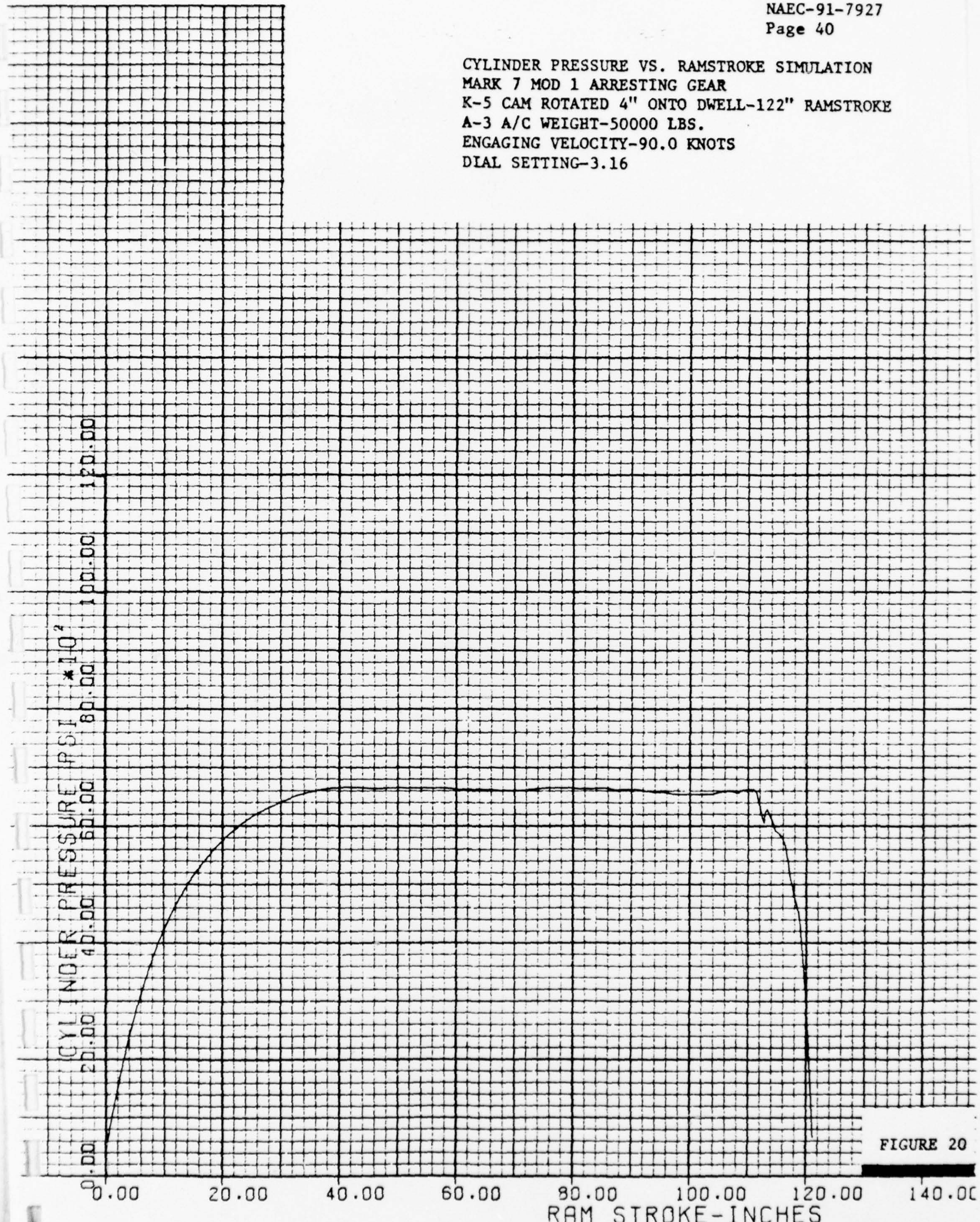


FIGURE 20

CYLINDER PRESSURE VS. RAM STROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
K-5 CAM ROTATED 4" ONTO DWELL-122" RAMSTROKE
A-3 A/C WEIGHT-50000 LBS.
ENGAGING VELOCITY-100.0 KNOTS
DIAL SETTING-3.16

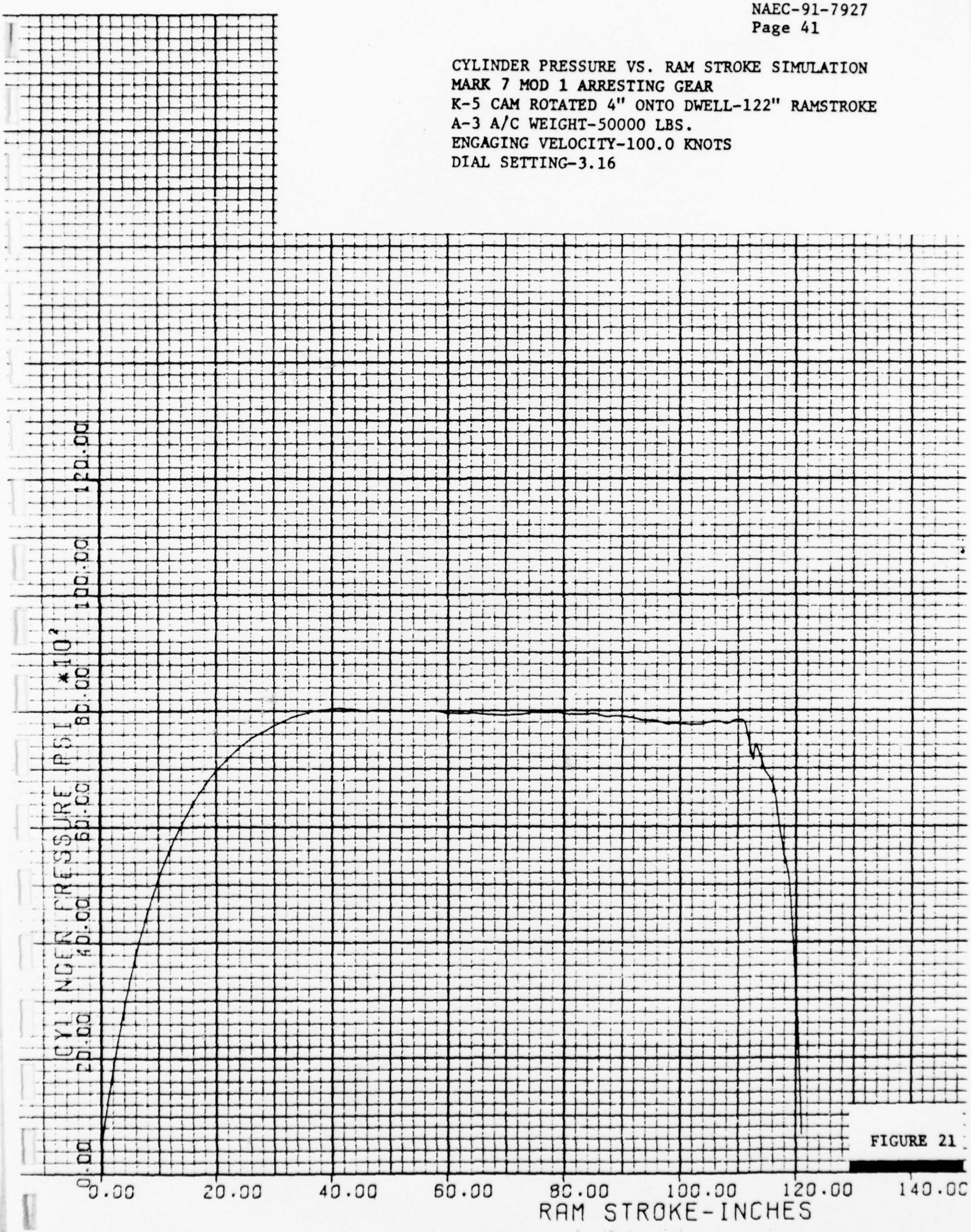


FIGURE 21

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
K-5 CAM ROTATED 4" ONTO DWELL-122" RAMSTROKE
A-3 A/C WEIGHT-50000 LBS.
ENGAGING VELOCITY-110.0 KNOTS
DIAL SETTING-3.16

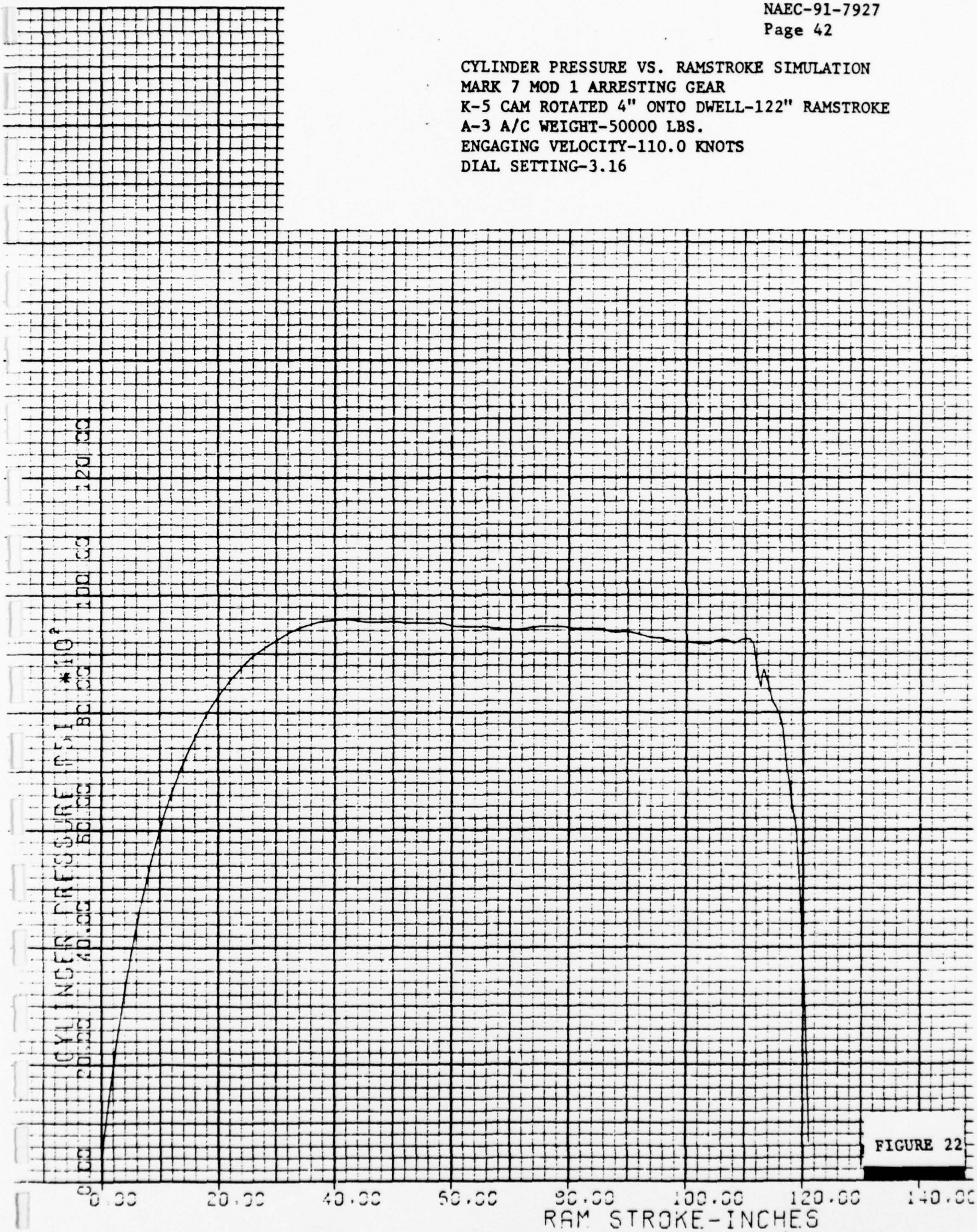


FIGURE 22

CYLINDER PRESSURE VS. RAM STROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
K-5 CAM ROTATED 4" ONTO DWELL-122" RAMSTROKE
A-3 A/C WEIGHT-500000 LBS.
ENGAGING VELOCITY-111.0 KNOTS.
DIAL SETTING-3.16

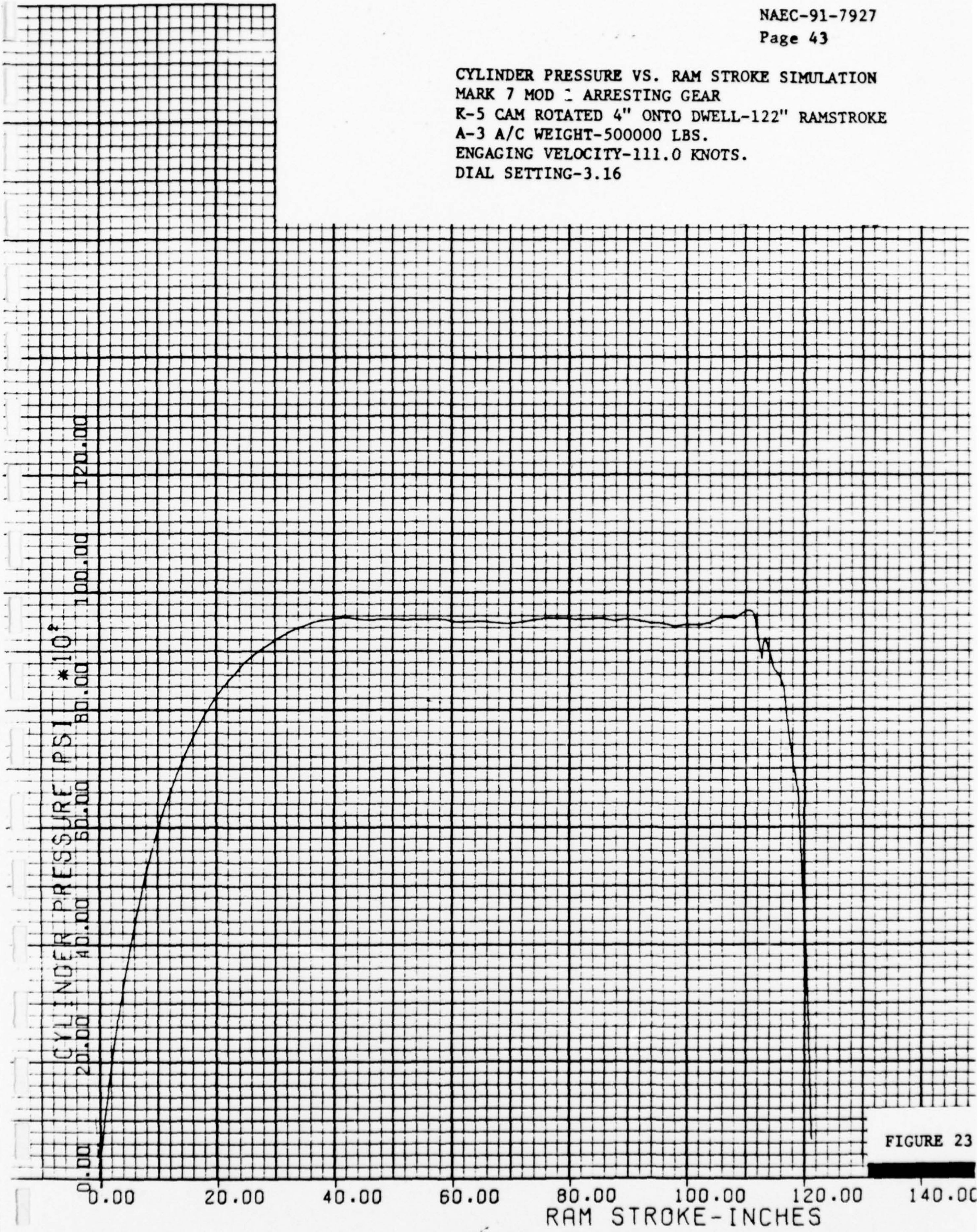


FIGURE 23

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
K-5 CAM ROTATED 4" ONTO DWELL-122" RAMSTROKE
A-3 A/C WEIGHT-50000 LBS.
ENGAGING VELOCITY-114 KNOTS
DIAL SETTING-3.16

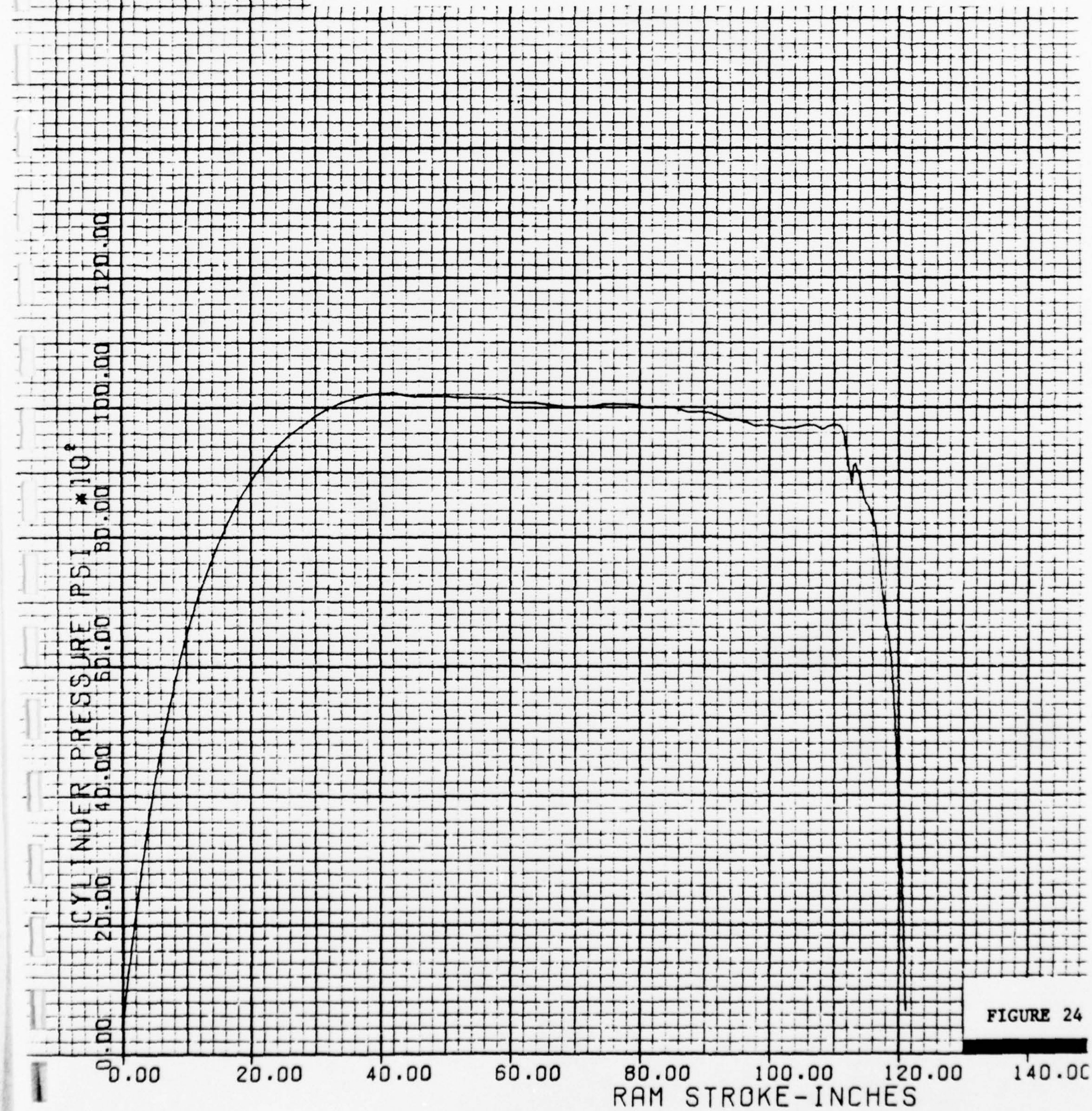


FIGURE 24

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
K-5 CAM ROTATED 8" ONTO DWELL-126" RAMSTROKE
A-3 A/C WEIGHT-50000 LBS.
ENGAGING VELOCITY-111 KNOTS
DIAL SETTING-3.16

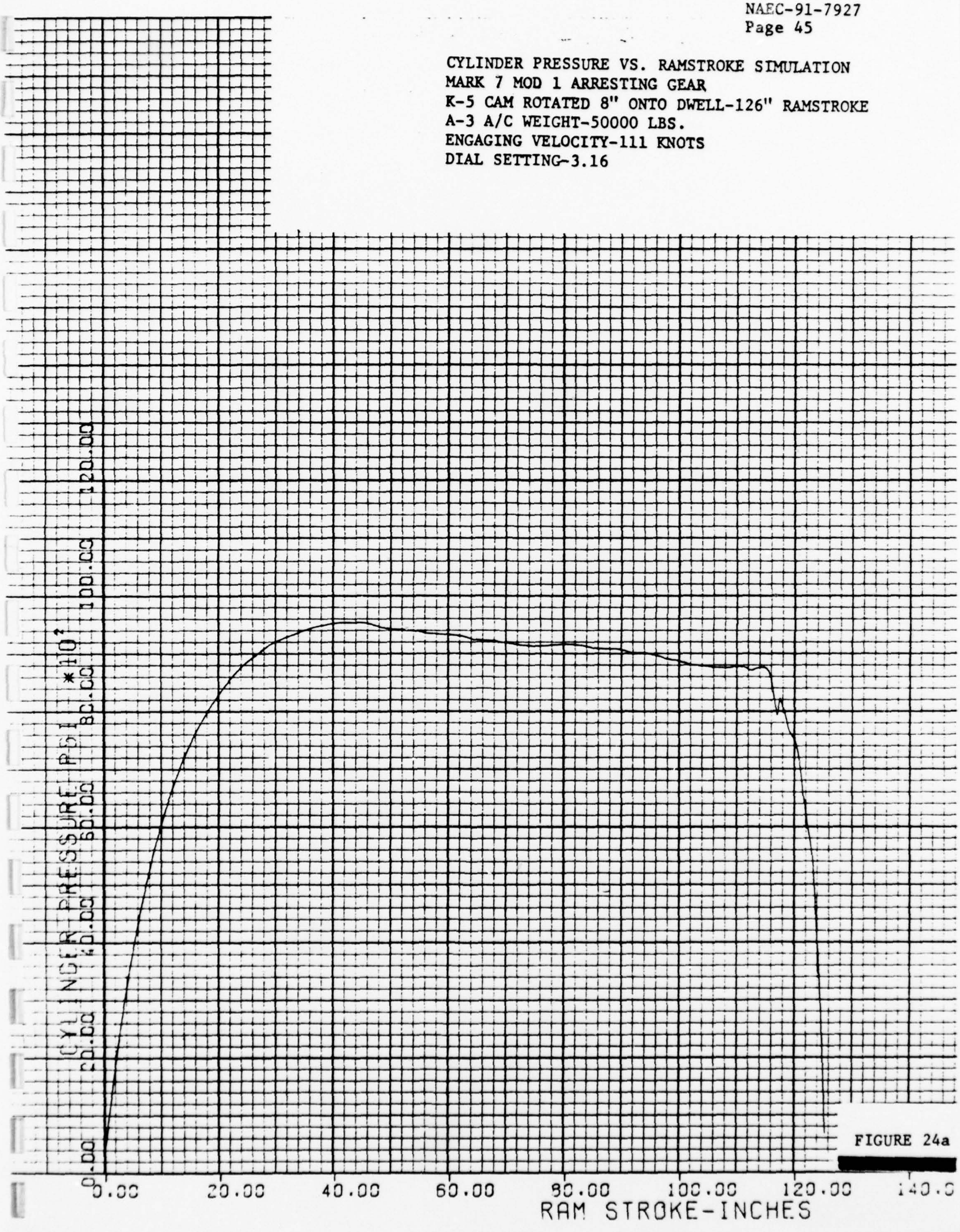


FIGURE 24a

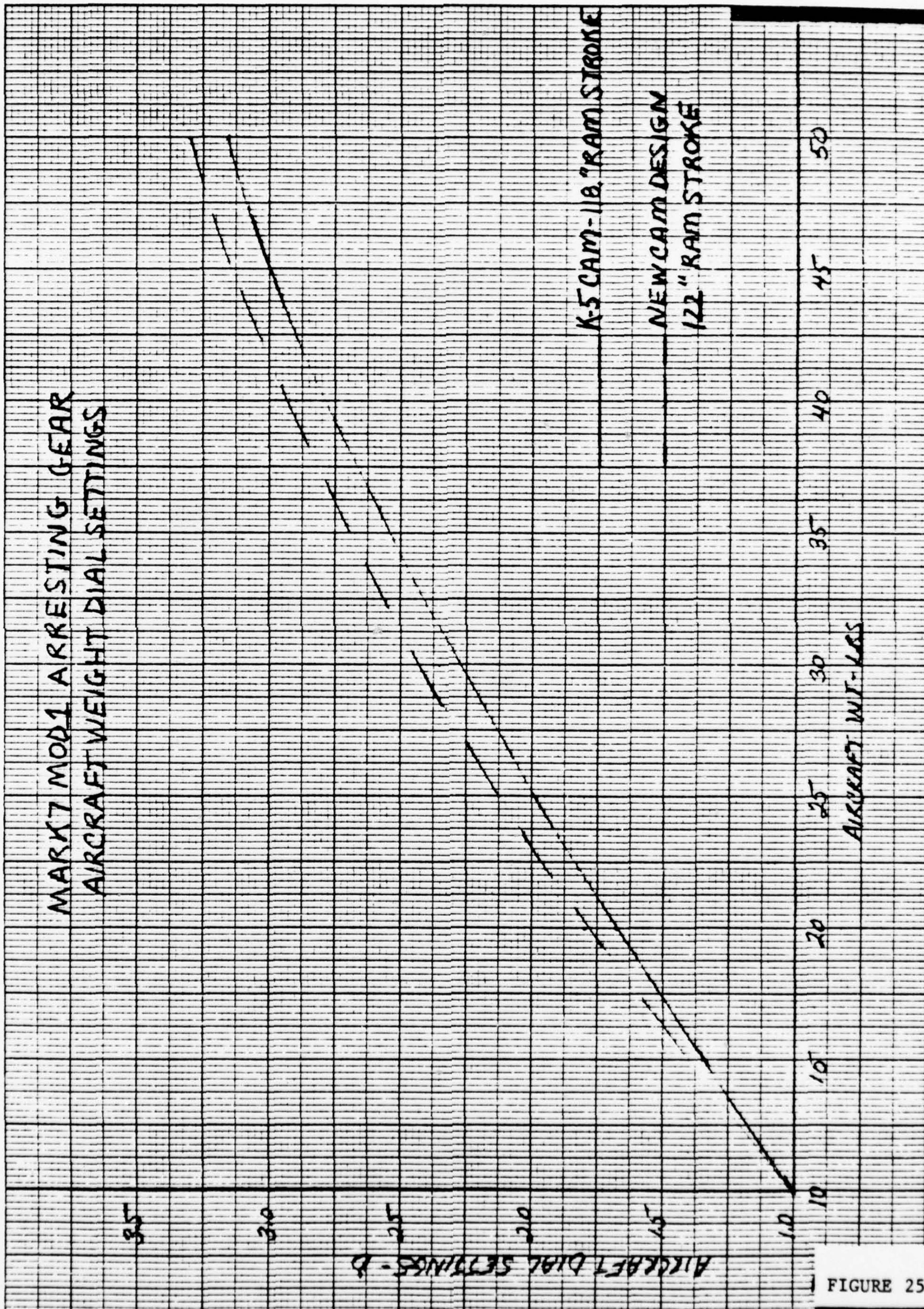

MARK 7 MOD 1 ARRESTING GEAR
AIRCRAFT WEIGHT DIAL SETTINGS
K-5 CAM-118" RAM STROKE
NEW CAM DESIGN
122" RAM STROKE
AIRCRAFT WT - KLBS
10
15
20
25
30
35
40
45
50
AIRCRAFT DIAL SETTINGS - D
1.0
1.5
2.0
2.5
3.0
3.5

FIGURE 25

CYLINDER PRESSURE VS. RAMSTROKE
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAM STROKE
A/C WEIGHT-13000 LBS.
ENGAGING VELOCITY-110.0 KNOTS
DIAL SETTING-1.25

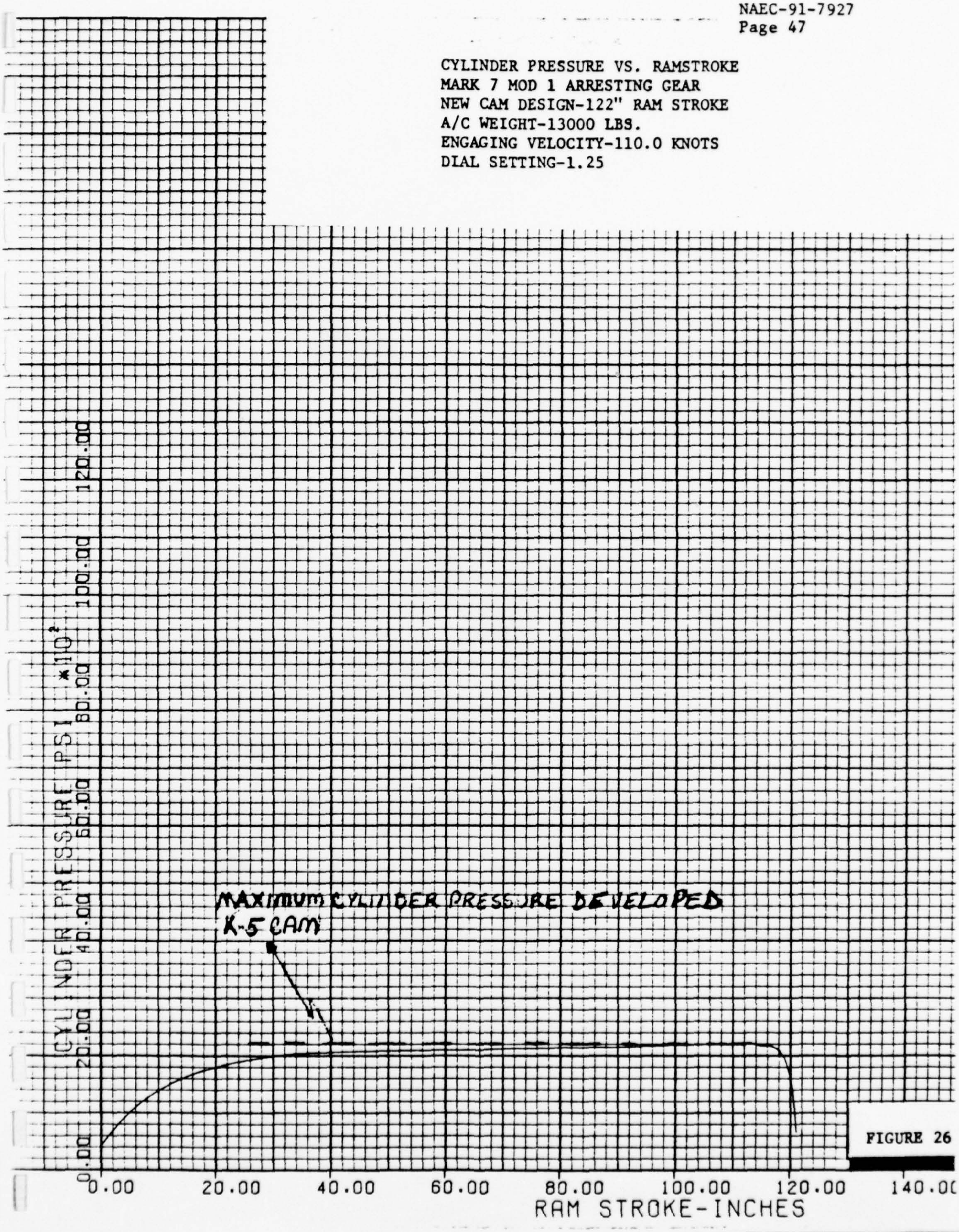


FIGURE 26

CYLINDER PRESSURE VS. RAMSTROKE
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
A/C WEIGHT-20000 LBS.
ENGAGING VELOCITY-110.0 KNOTS
DIAL SETTING-1.80

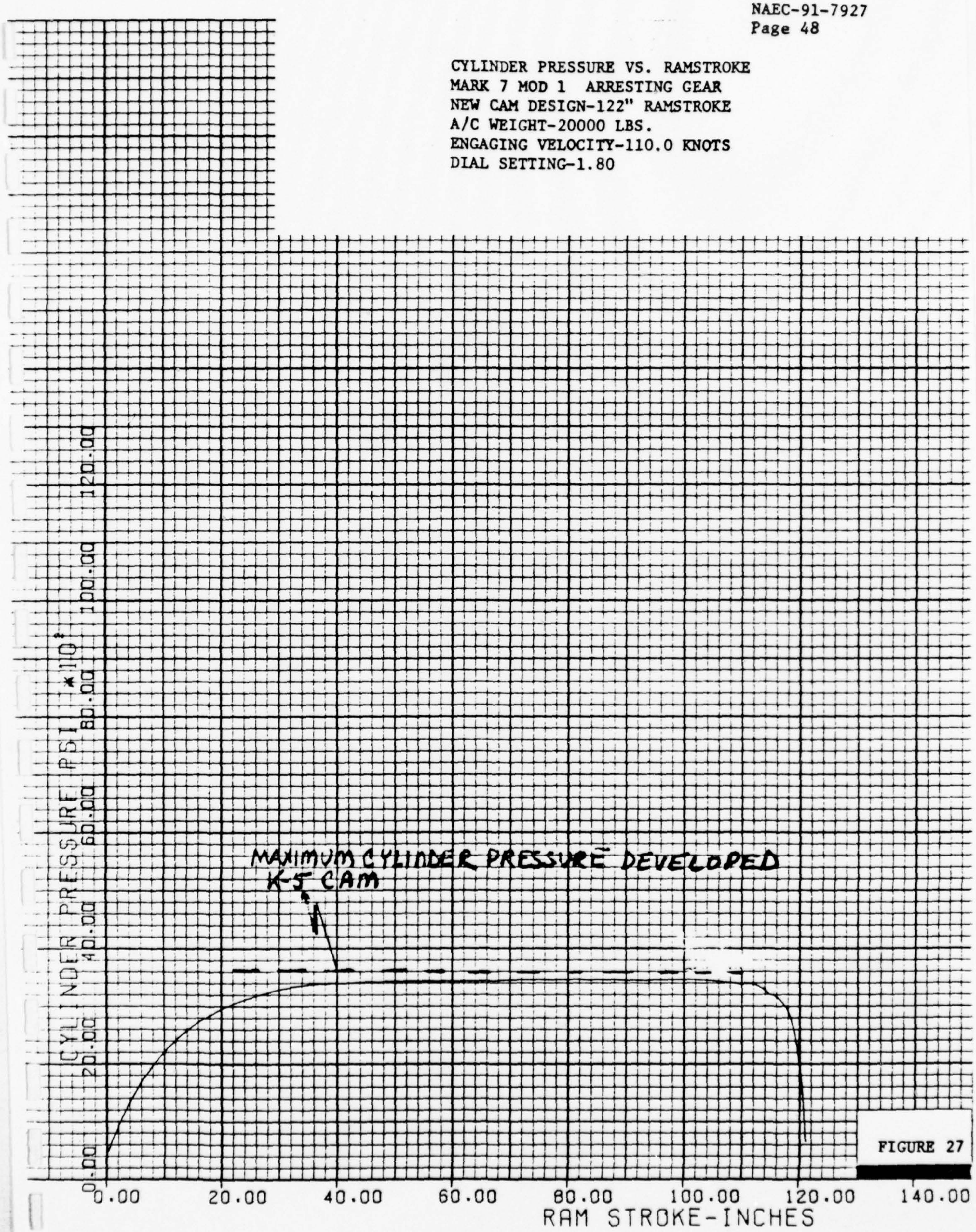


FIGURE 27

CYLINDER PRESSURE VS. RAMSTROKE
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
A/C WEIGHT-30000 LBS.
ENGAGING VELOCITY-110.0 KNOTS
DIAL SETTING-2.4

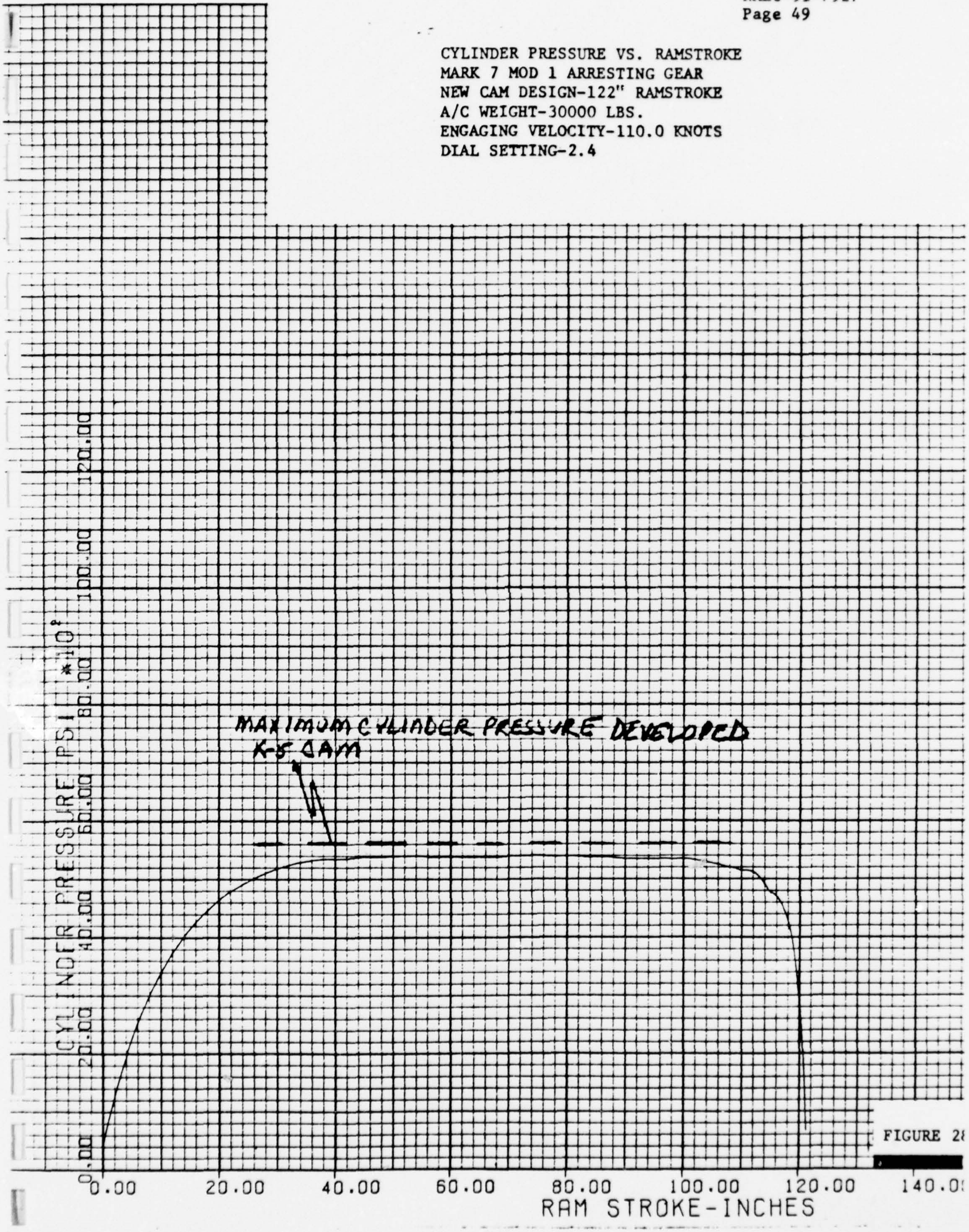


FIGURE 28

CYLINDER PRESSURE VS. RAM STROKE
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
A/C WEIGHT-40000 LBS.
ENGAGING VELOCITY-110.0 KNOTS
DIAL SETTING-2.9

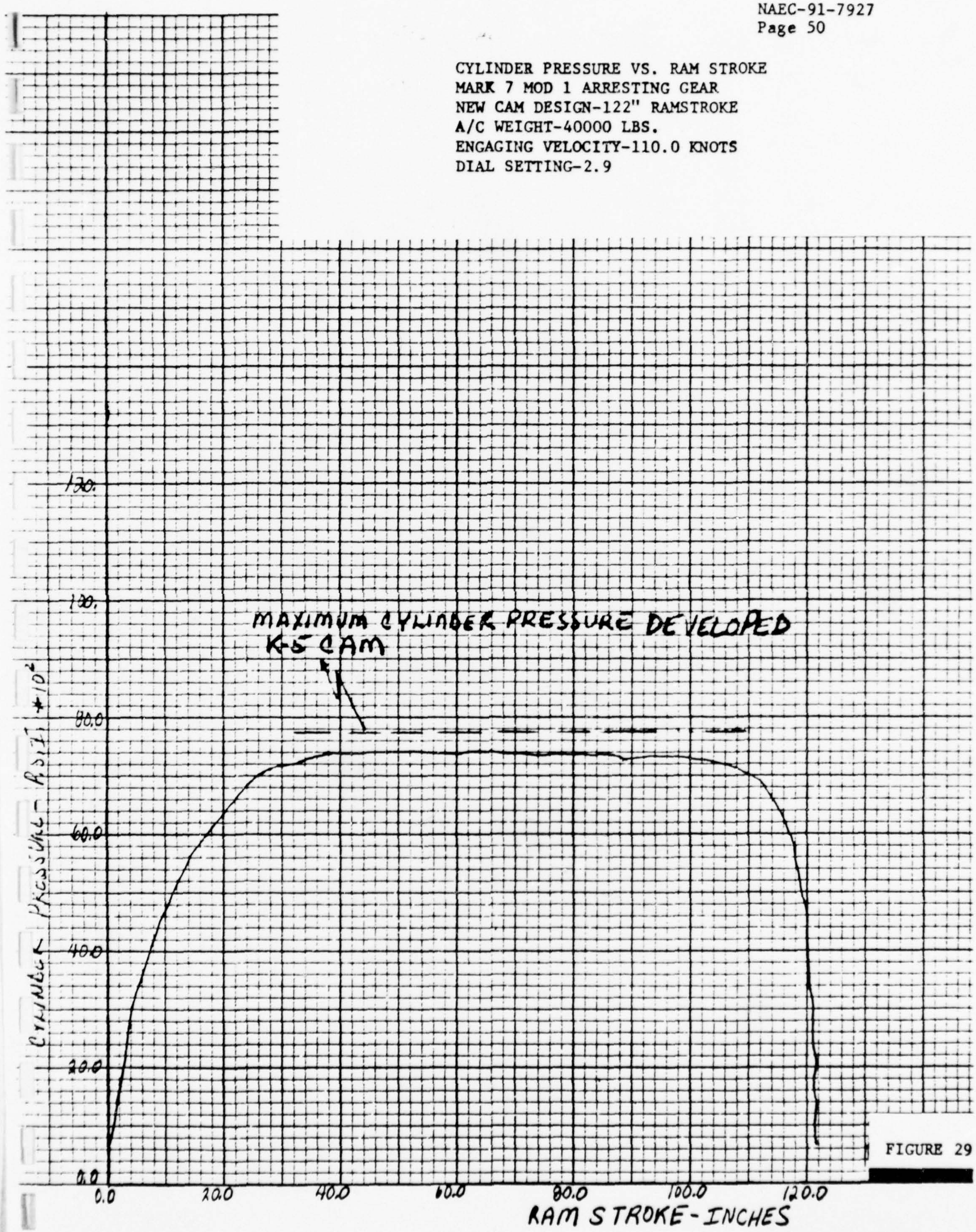


FIGURE 29

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
F-4J A/C WEIGHT-37000 LBS.
ENGAGING VELOCITY-116 KNOTS
DIAL SETTING-2.75
THRUST-.4 WEIGHT

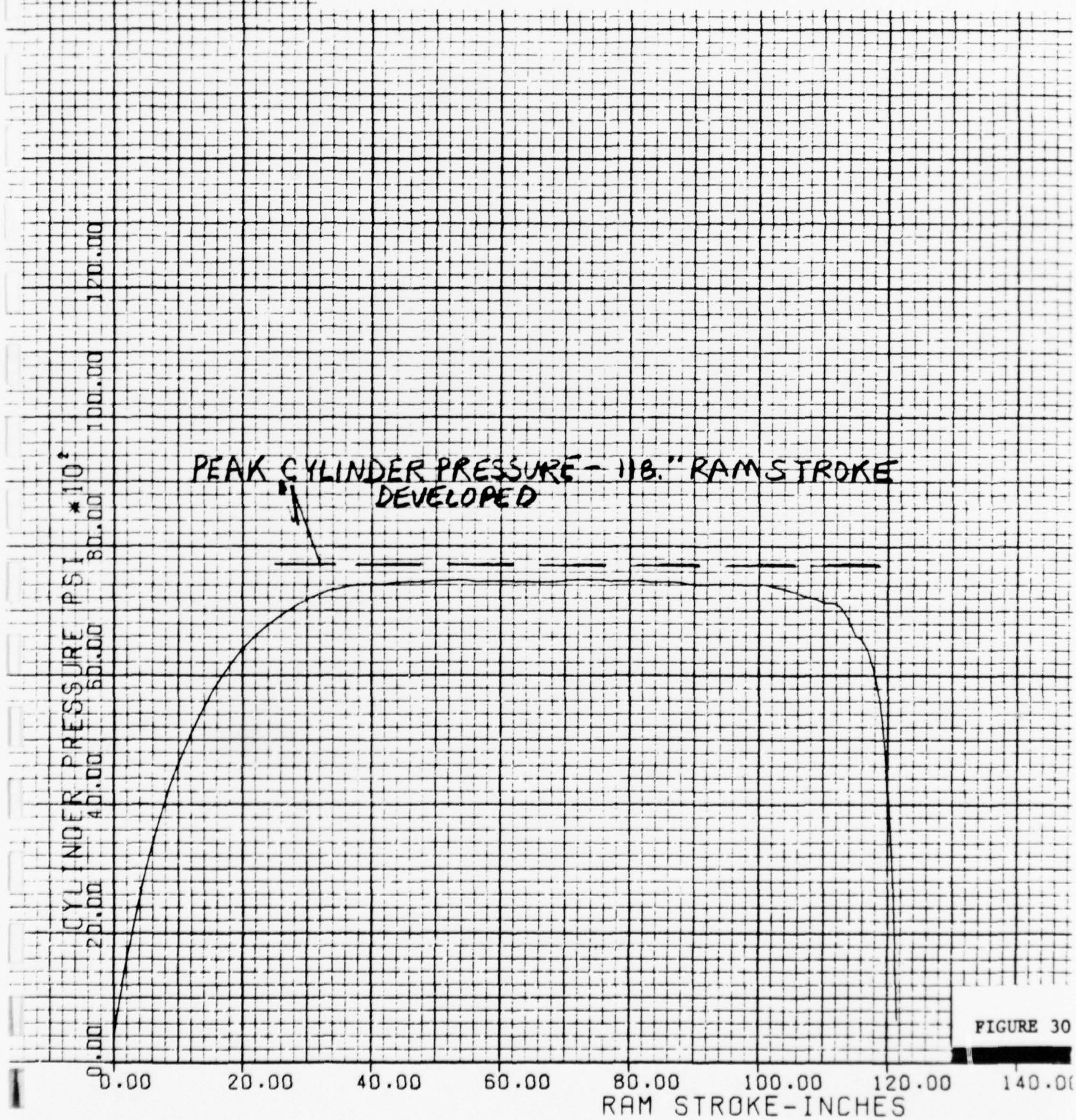


FIGURE 30

CYLINDER PRESSURE VS. RAM STROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
F-4J A/C WEIGHT-37000 LBS.
ENGAGING VELOCITY-116 KNOTS
DIAL SETTINGS-2.75
THRUST-.63 WEIGHT

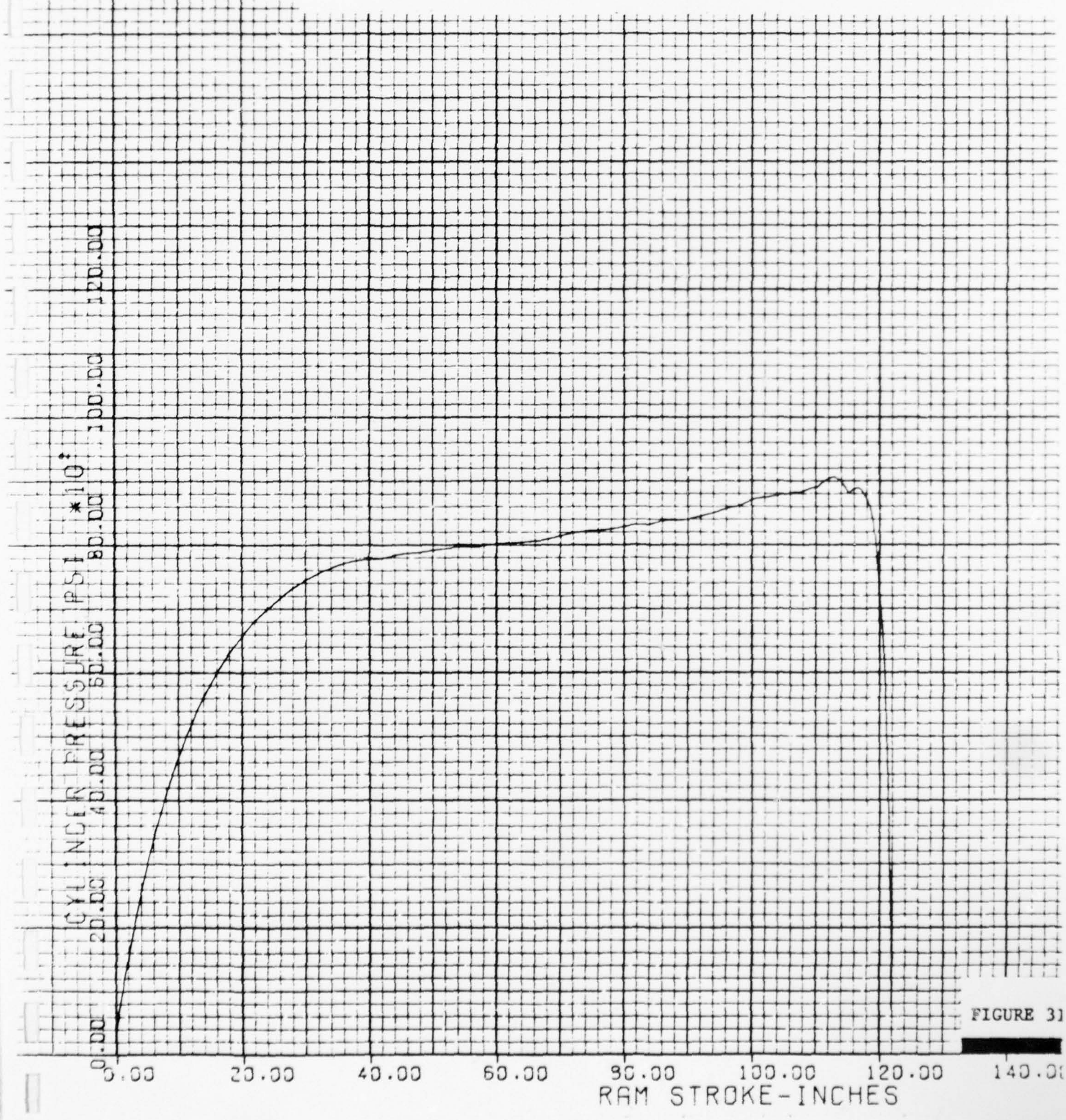


FIGURE 31

CYLINDER PRESSURE VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
K-5 CAM ROTATED 4" ONTO DWELL-122" RAMSTROKE
F-4J A/C WEIGHT-37000 LBS.
ENGAGING VELOCITY-116 KNOTS
DIAL SETTING-2.55
THRUST-.63 WEIGHT

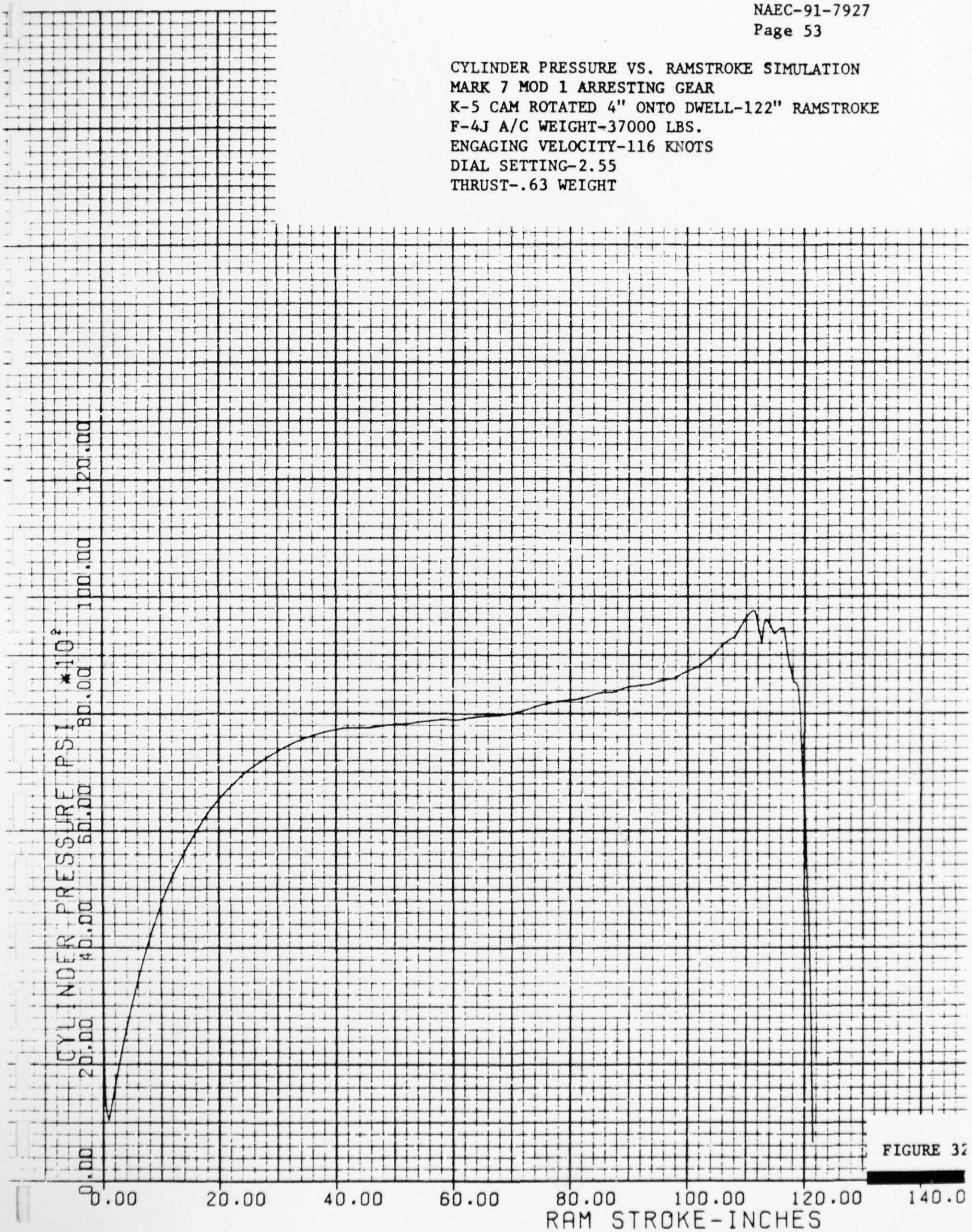


FIGURE 32

CABLE TENSION VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
F-4J A/C WEIGHT-37000 LBS.
ENGAGING VELOCITY-116 KNOTS
DIAL SETTING-2.75
THRUST-.4x WEIGHT

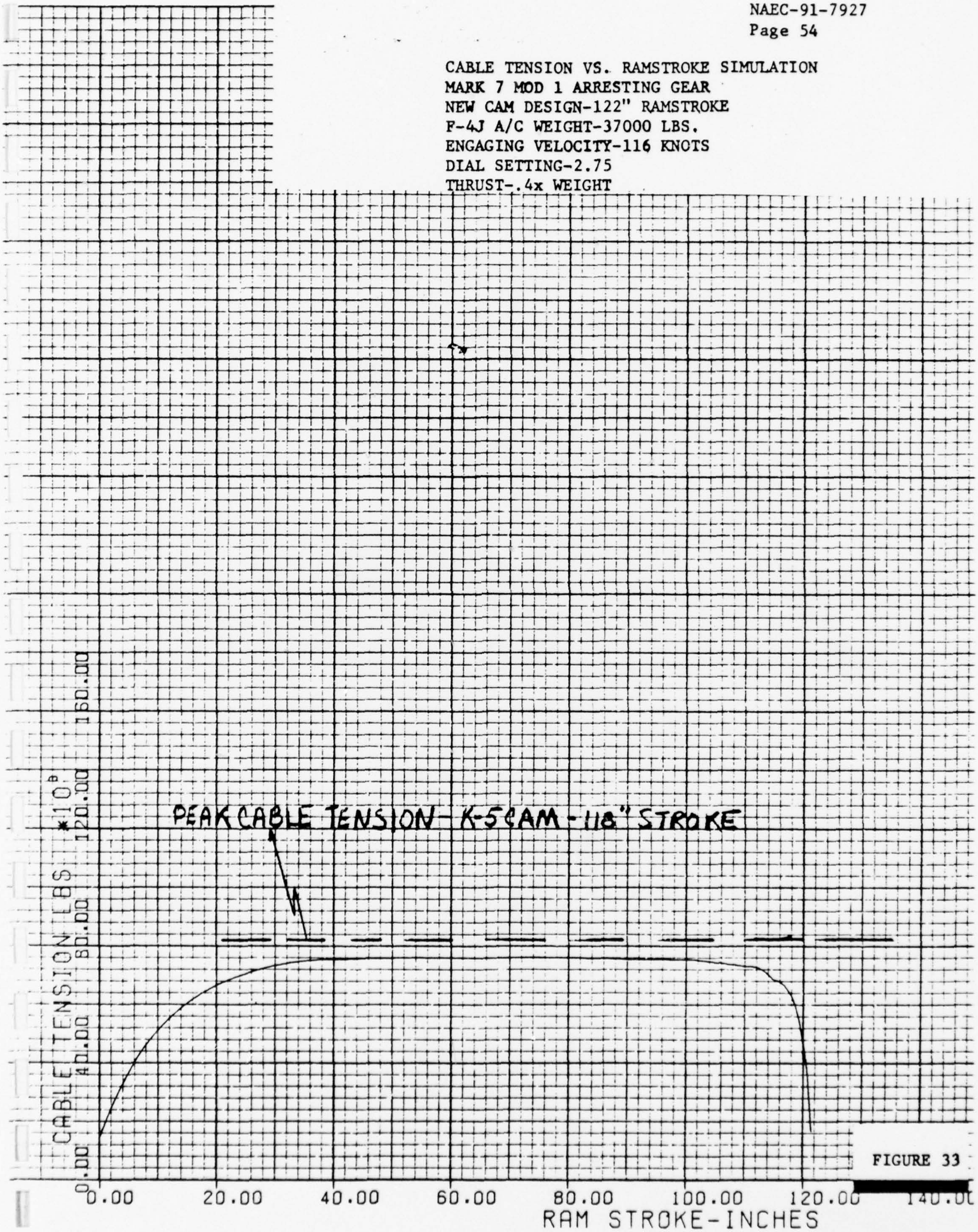


FIGURE 33

HOOKLOAD VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
F-4J A/C WEIGHT-37000 LBS.
ENGAGING VELOCITY-116 KNOTS
DIAL SETTING-2.75
THRUST-.4x WEIGHT

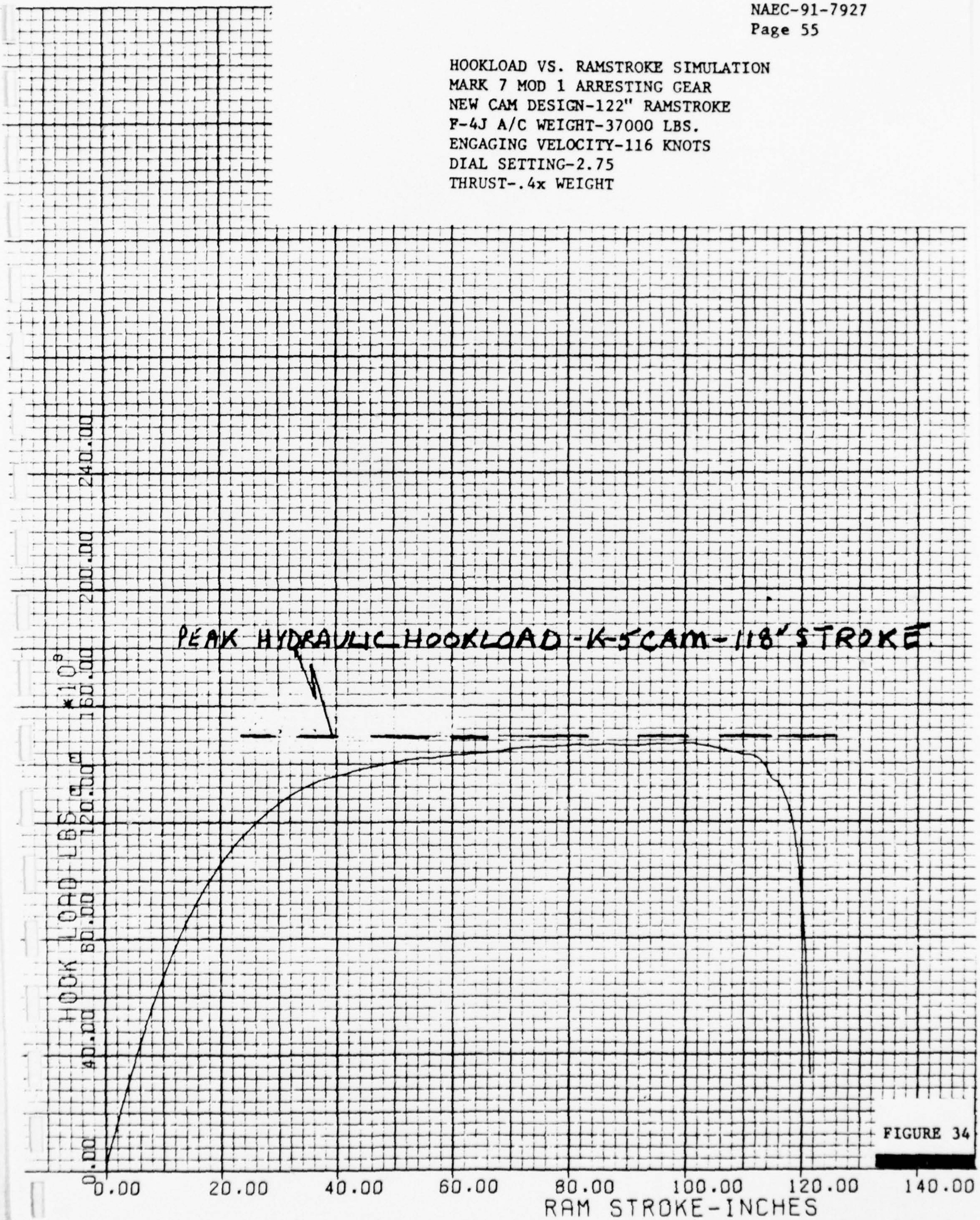


FIGURE 34

CABLE TENSION VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
F-4J A/C WEIGHT-37000 LBS.
ENGAGING VELOCITY-116 KNOTS
DIAL SETTING-2.75
THRUST-.63x WEIGHT

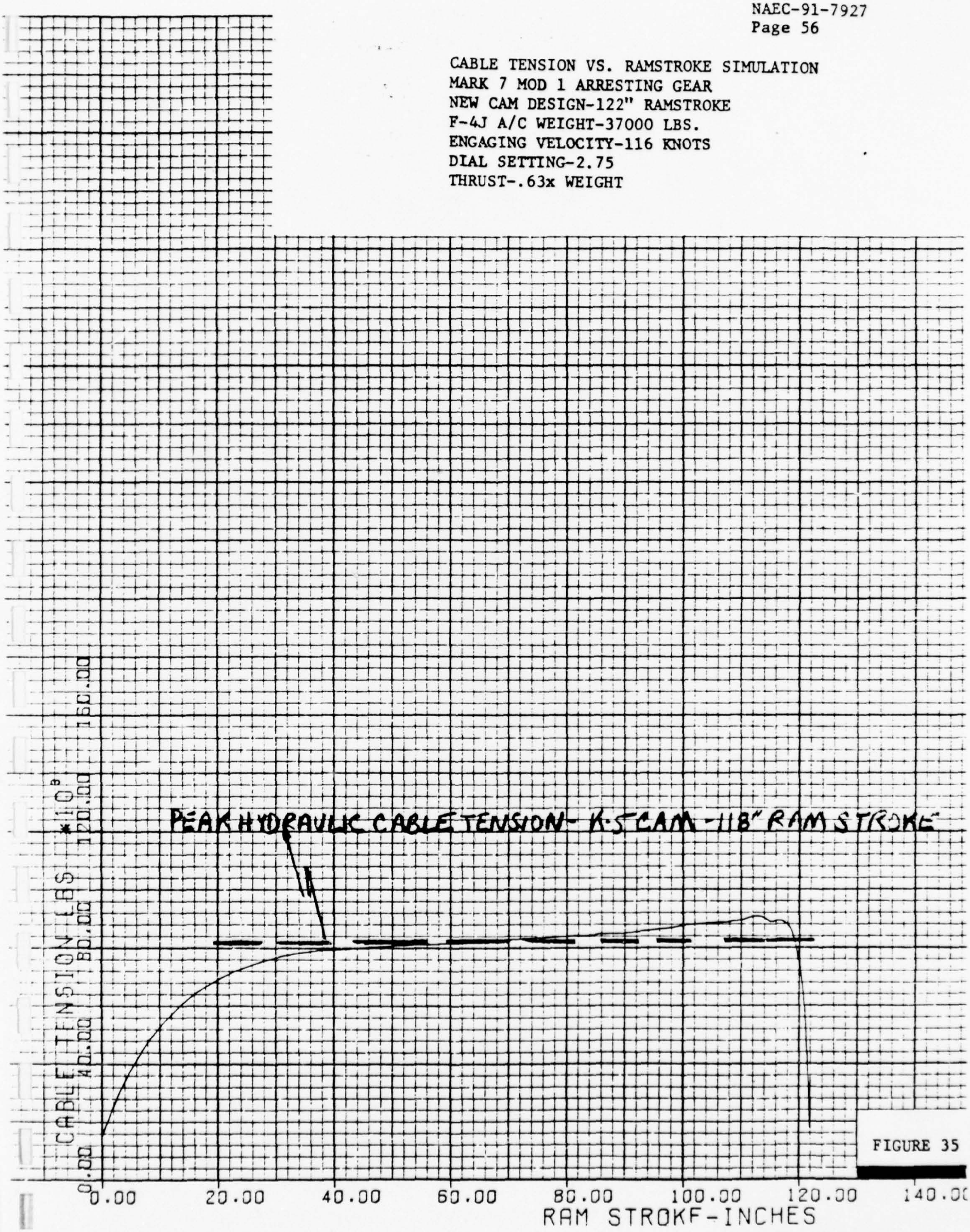


FIGURE 35

HOOKLOAD VS. RAMSTROKE SIMULATION
MARK 7 MOD 1 ARRESTING GEAR
NEW CAM DESIGN-122" RAMSTROKE
F-4J A/C WEIGHT-37000 LBS.
ENGAGING VELOCITY-116 KNOTS
DIAL SETTING-2.75
THRUST-.63x WEIGHT

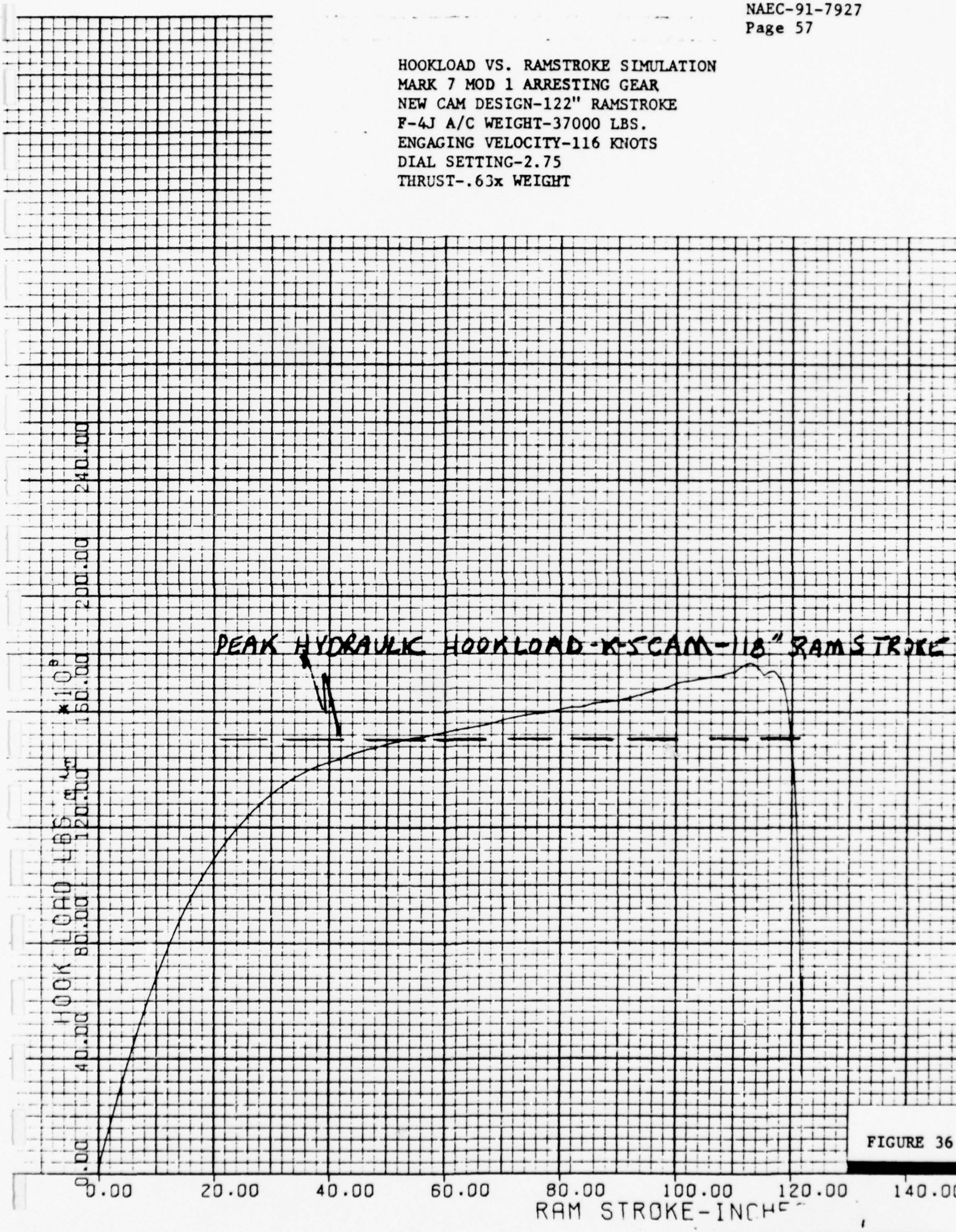


FIGURE 36

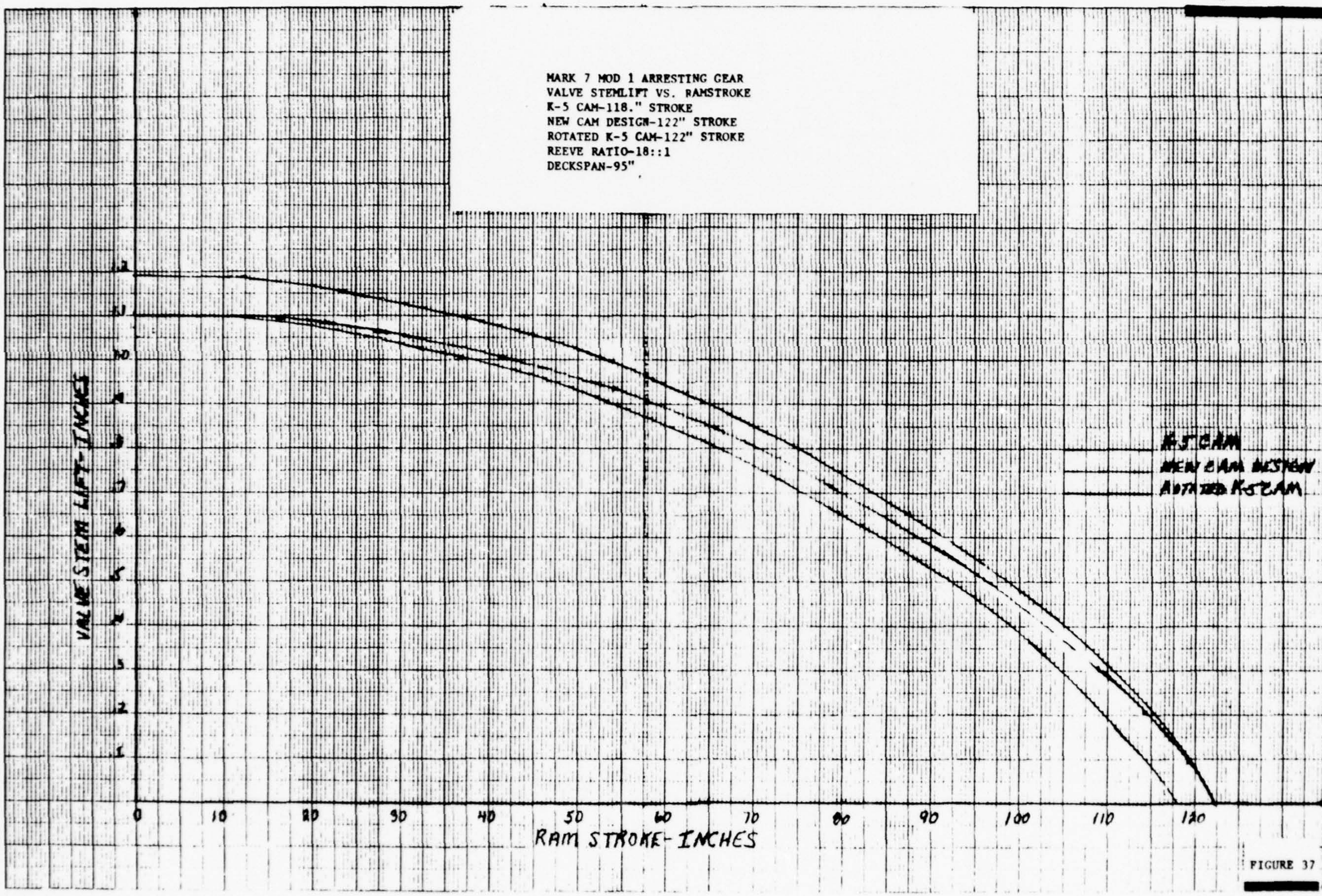

MARK 7 MOD 1 ARRESTING GEAR
VALVE STEMLIFT VS. RAMSTROKE
K-5 CAM-118." STROKE
NEW CAM DESIGN-122" STROKE
ROTATED K-5 CAM-122" STROKE
REEVE RATIO-18::1
DECKSPAN-95"
K-5 CAM
NEW CAM DESIGN
ROTATED K-5 CAM
VALVE STEM LIFT-INCHES
RAM STROKE-INCHES
0
10
20
30
40
50
60
70
80
90
100
110
120

FIGURE 37

TABLE 1

MARK 7 MOD 1 ARRESTING GEAR
VALVE STEM LIFT VS RAM STROKE CO-ORDINATES
STANDARD K-5 CAM - 118.1 STROKE DECKSPAN 95'

STROKE	LIFT.		STROKE	LIFT		STROKE	LIFT		
0.0	1.10		60.42	.853		110.83	.190		
2.08	1.10		62.50	.836		111.67	.170		
4.17	1.10		64.58	.813		112.50	.150		
6.25	1.10		66.67	.798		113.33	.135		
8.33	1.10		68.75	.776		114.17	.115		
10.42	1.099		70.83	.753		115.0	.090		
12.50	1.095		72.92	.731		115.83	.070		
14.58	1.090		75.0	.709		116.67	.045		
16.67	1.085		77.08	.688		117.08	.030		
18.75	1.080		79.17	.664		117.50	.015		
20.83	1.072		81.25	.639		117.9	.005		
22.92	1.066		83.33	.617		118.1	.000		
25.0	1.059		85.42	.590					
27.08	1.050		87.50	.565					
29.17	1.040		89.58	.540					
31.25	1.031		91.67	.512					
33.33	1.021		93.75	.485					
35.42	1.012		95.83	.454					
37.50	1.002		97.9	.423					
39.58	.995		100.0	.389					
41.67	.986		102.08	.352					
43.75	.973		104.17	.316					
45.83	.960		105.0	.299					
47.92	.948		105.83	.282					
50.0	.933		106.07	.265					
52.08	.918		107.5	.249					
54.17	.902		109.85	.235					
56.25	.889		109.17	.220					
58.33	.871		110.0	.205					

TABLE 2

MARK 7 MOD 1 ARRESTING GEAR
VALVE STEM LIFT vs RAM STROKE COORDINATES
NEW CAM DESIGN- 122" STROKE DECK SPAN-95'

STROKE	LIFT		STROKE	LIFT		STROKE	LIFT		
0.0	1.19		60.42	.943		121.5	.032		
2.08	1.19		62.50	.926		122.0	.000		
4.17	1.19		64.58	.908					
6.25	1.19		66.67	.888					
8.33	1.19		68.75	.866					
10.42	1.189		70.83	.843					
12.50	1.185		72.92	.821					
14.58	1.180		75.0	.799					
16.67	1.175		77.08	.778					
18.75	1.170		79.17	.754					
20.83	1.162		81.25	.729					
22.92	1.156		83.33	.707					
25.00	1.149		85.42	.680					
27.08	1.140		87.50	.655					
29.17	1.130		89.58	.630					
31.25	1.121		91.67	.602					
33.33	1.111		93.75	.573					
35.42	1.102		95.83	.543					
37.50	1.092		97.92	.513					
39.58	1.085		100.0	.480					
41.67	1.076		102.5	.442					
43.75	1.063		105.0	.402					
45.83	1.050		107.5	.360					
47.92	1.038		110.0	.314					
50.0	1.023		112.5	.262					
52.08	1.008		115.0	.213					
54.17	.992		117.5	.150					
56.25	.979		120.0	.082					
58.33	.961		121.0	.048					

TABLE 3

MARK 7 MOD 1 ARRESTING GEAR VALVE STEMLIFT VS RAM STROKE CO-ORDINATES ROTATED K-5 CAM 122" STROKE · DECKSPAN - 95'							
STROKE	LIFT	STROKE	LIFT	STROKE	LIFT		
0.0	1.10	56.08	.918	111.5	.249		
1.0	1.10	58.17	.902	112.83	.235		
2.0	1.10	60.25	.887	113.17	.220		
3.0	1.10	62.33	.871	114.0	.205		
4.0	1.10	64.42	.853	114.83	.190		
6.08	1.10	66.50	.836	115.67	.170		
8.17	1.10	68.58	.818	116.50	.150		
10.25	1.10	70.67	.798	117.33	.135		
12.33	1.10	72.75	.776	118.17	.115		
14.42	1.099	74.83	.753	119.0	.090		
16.50	1.095	76.92	.731	119.83	.070		
18.58	1.090	79.0	.709	120.67	.045		
20.67	1.085	81.08	.688	121.08	.030		
22.75	1.080	83.17	.664	121.50	.015		
24.83	1.072	85.25	.639	121.9	.005		
26.92	1.066	87.33	.617	122.0	.000		
29.0	1.059	89.42	.590				
31.08	1.050	91.50	.565				
33.17	1.040	93.58	.540				
35.25	1.031	95.67	.512				
37.33	1.021	97.75	.485				
39.42	1.012	99.83	.454				
41.50	1.002	101.92	.423				
43.58	.995	104.0	.389				
45.67	.986	106.08	.352				
47.75	.973	108.17	.316				
49.83	.960	109.0	.299				
51.92	.948	109.83	.282				
54.0	.933	110.67	.265				

Geometrical vs. Effective Flow Area, MK 7 Mod 1 Arresting Gear

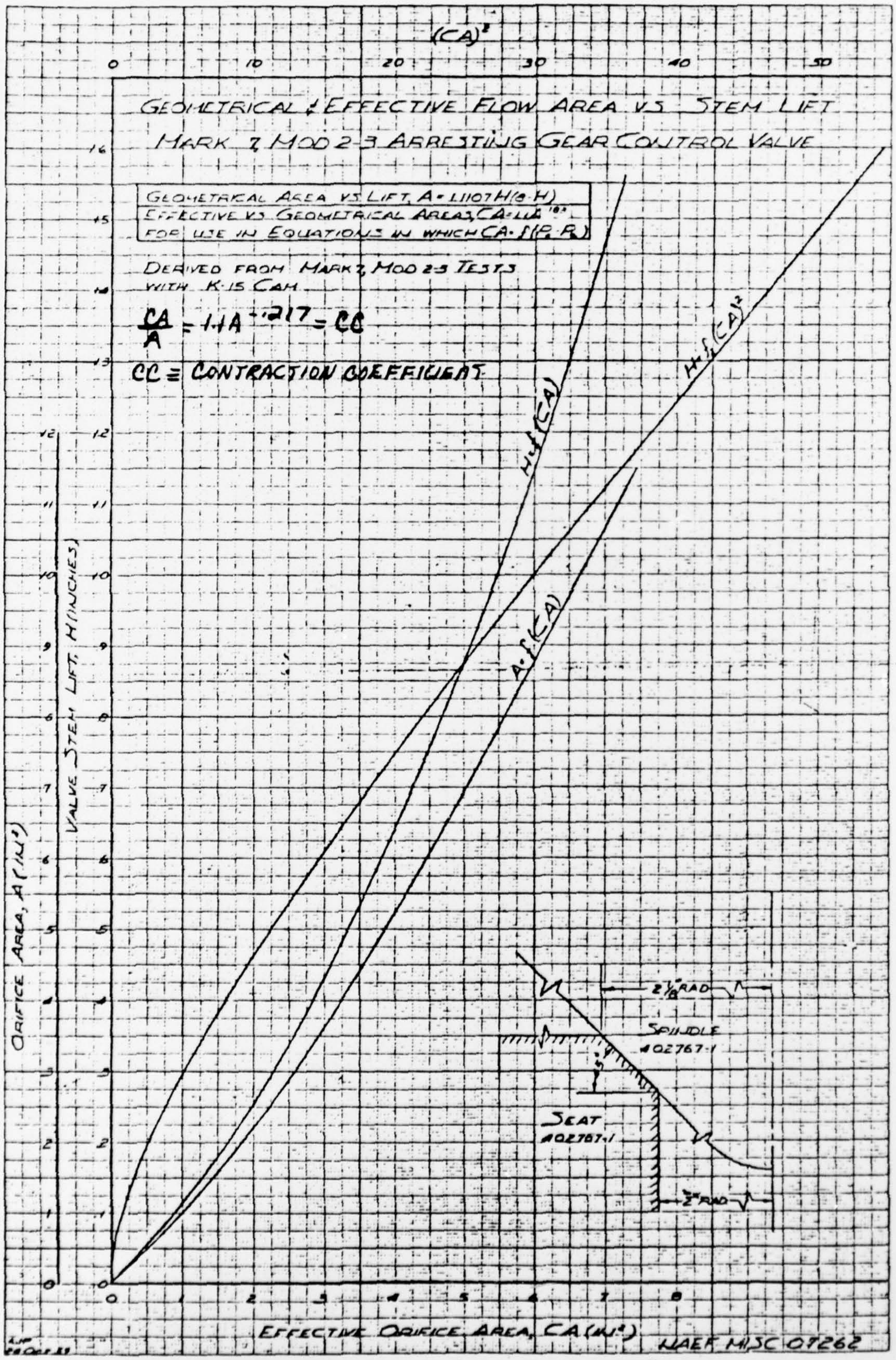


FIGURE 38

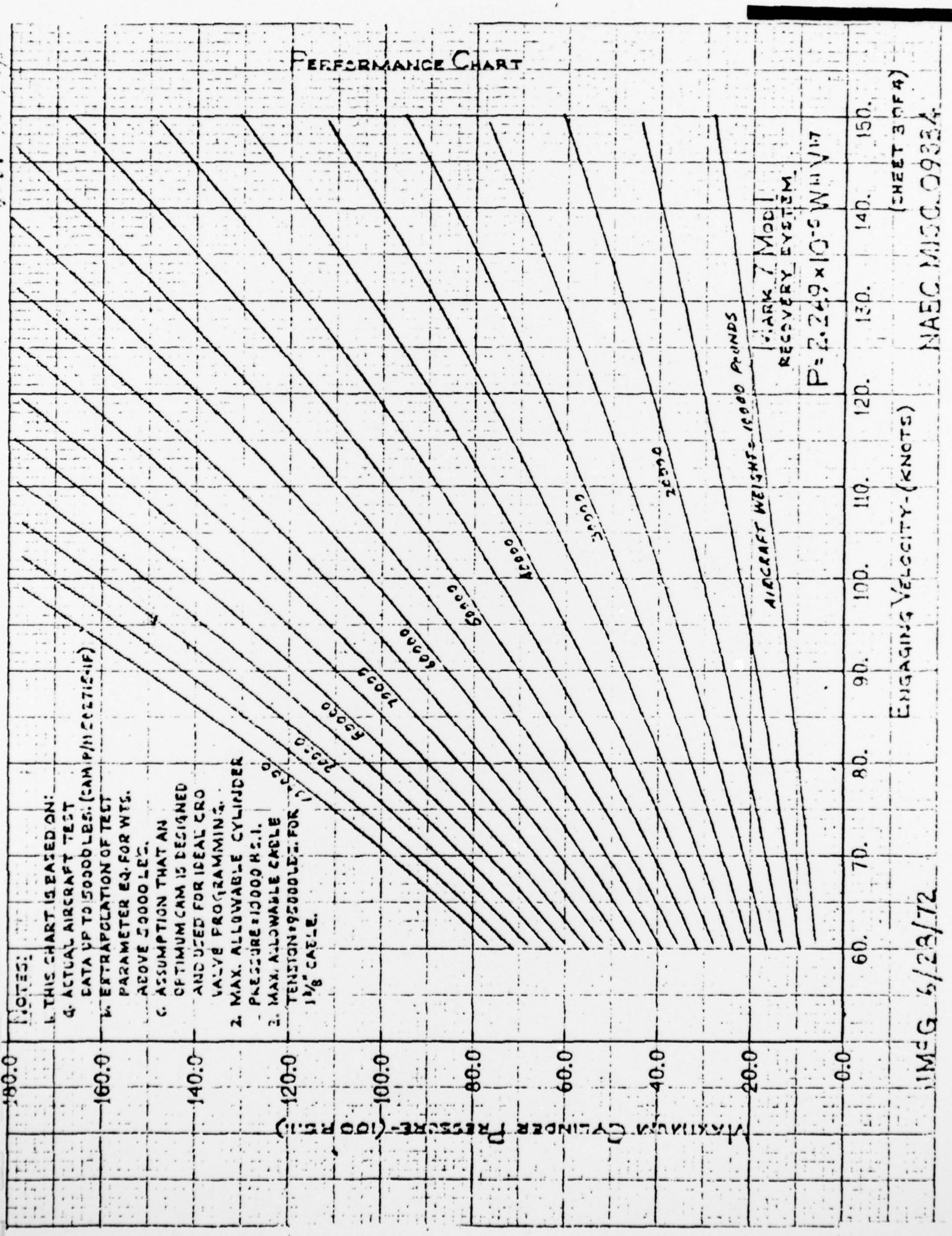

PERFORMANCE CHART
NOTES:
1. THIS CHART IS BASED ON:
a. ACTUAL AIRCRAFT TEST DATA UP TO 50000 LBS.
b. EXTRAPOLATION OF TEST PARAMETER EQ. FOR WTS. ABOVE 50000 LBS.
c. ASSUMPTION THAT AN OPTIMUM CAM IS DESIGNED AND USED FOR IDEAL CRO VALVE PROGRAMMING.
2. MAX. ALLOWABLE CYLINDER PRESSURE = 13000 P.S.I.
3. MAX. ALLOWABLE CABLE TENSION = 95000 LBS. FOR 1 3/8" CABLE.
AIRCRAFT WEIGHT = 10000 POUNDS
20000
30000
40000
50000
60000
70000
80000
MARK 7 MOD 1
RECOVERY SYSTEM
ENGAGING VELOCITY - (KNOTS)
MAXIMUM CYLINDER PRESSURE - (100 P.S.I.)
60. 70. 80. 90. 100. 110. 120. 130. 140. 150.
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
(SHEET 3 OF 4)
NAEC MISC 0933A
6/28/72

FIGURE 39

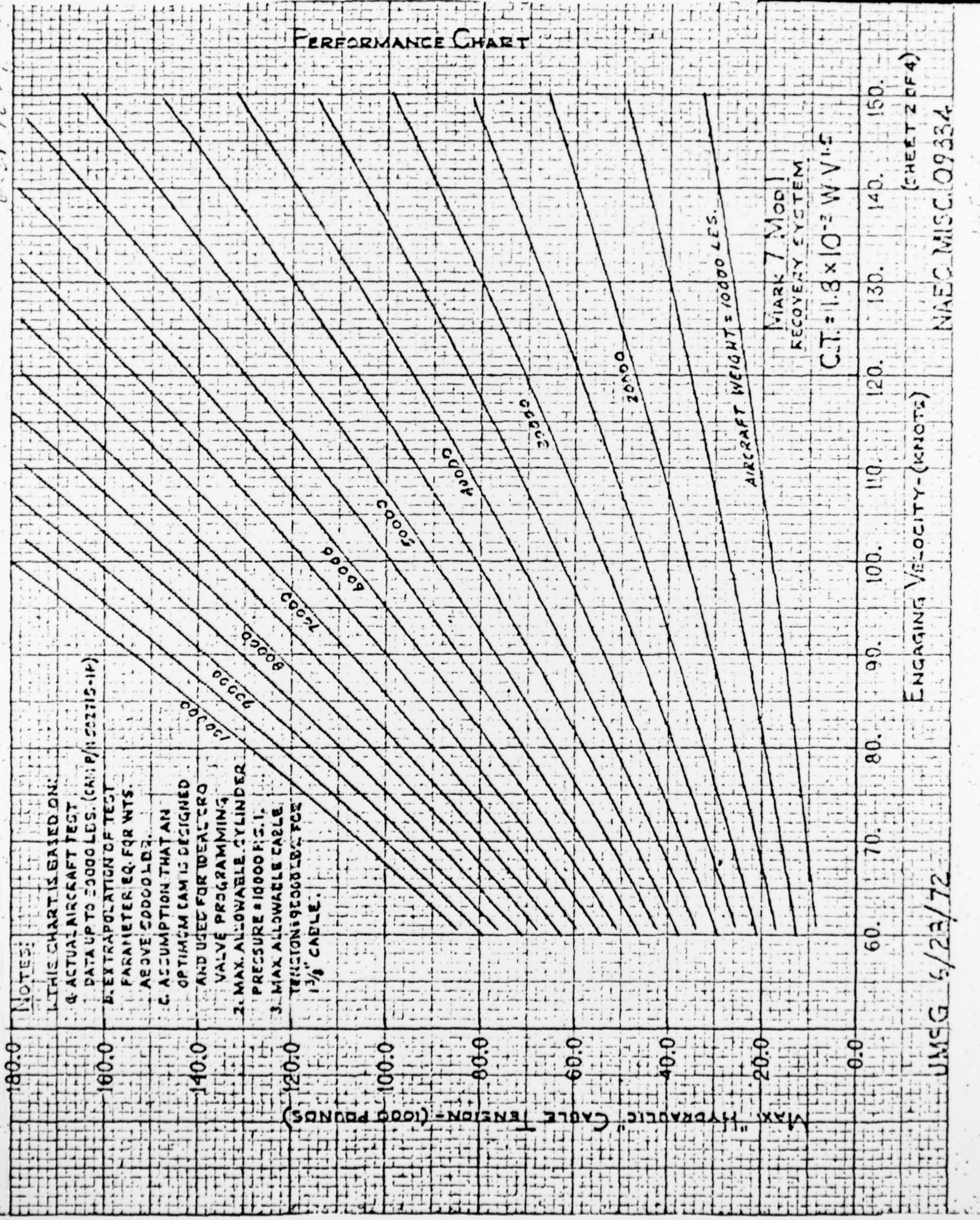

PERFORMANCE CHART
NOTES:
1. THIS CHART IS BASED ON:
a. ACTUAL AIRCRAFT TEST DATA UP TO 50000 LBS.
b. EXTRAPOLATION OF TEST PARAMETER EQ. FOR WTS. ABOVE 50000 LBS.
c. ASSUMPTION THAT AN OPTIMUM CAM IS DESIGNED AND USED FOR IDEAL ZERO VALVE PROGRAMMING
2. MAX. ALLOWABLE CYLINDER PRESSURE = 10000 P.S.I.
3. MAX. ALLOWABLE CABLE TENSION = 95000 LBS. FOR 1 3/8" CABLE.
AIRCRAFT WEIGHT = 10000 LBS.
20000
30000
40000
50000
60000
70000
80000
90000
100000
MARK 7 MOD 1
RECOVERY SYSTEM
C.T. = 1.8 x 10^-3 W V^1.5
NAEC MISC 09334
(SHEET 2 OF 4)
UMSG 6/23/72
ENGAGING VELOCITY - (KNOTS)
60. 70. 80. 90. 100. 110. 120. 130. 140. 150.
MAX. "HYDRAULIC" CABLE TENSION - (1000 POUNDS)
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
6-28-72

FIGURE 40

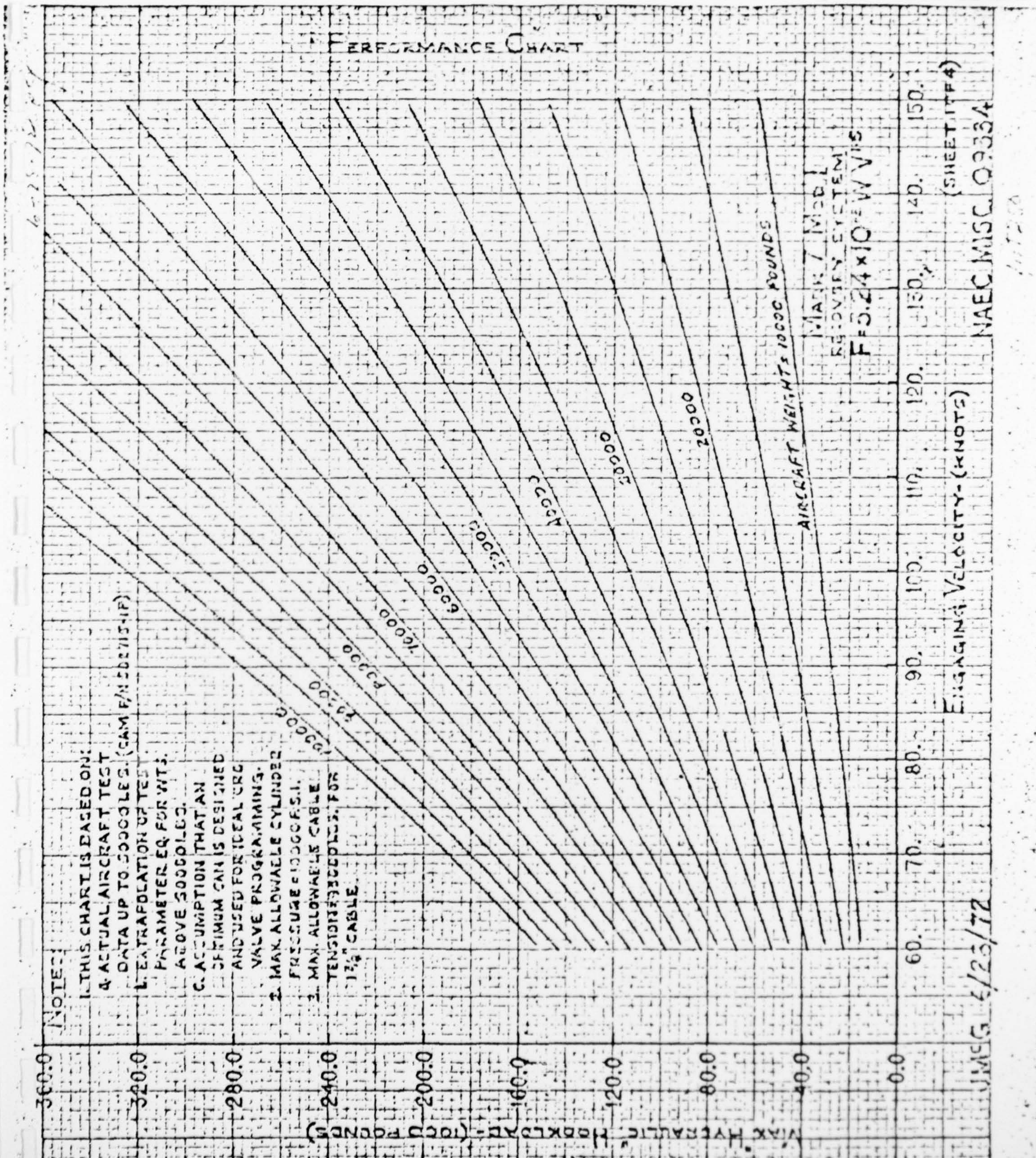
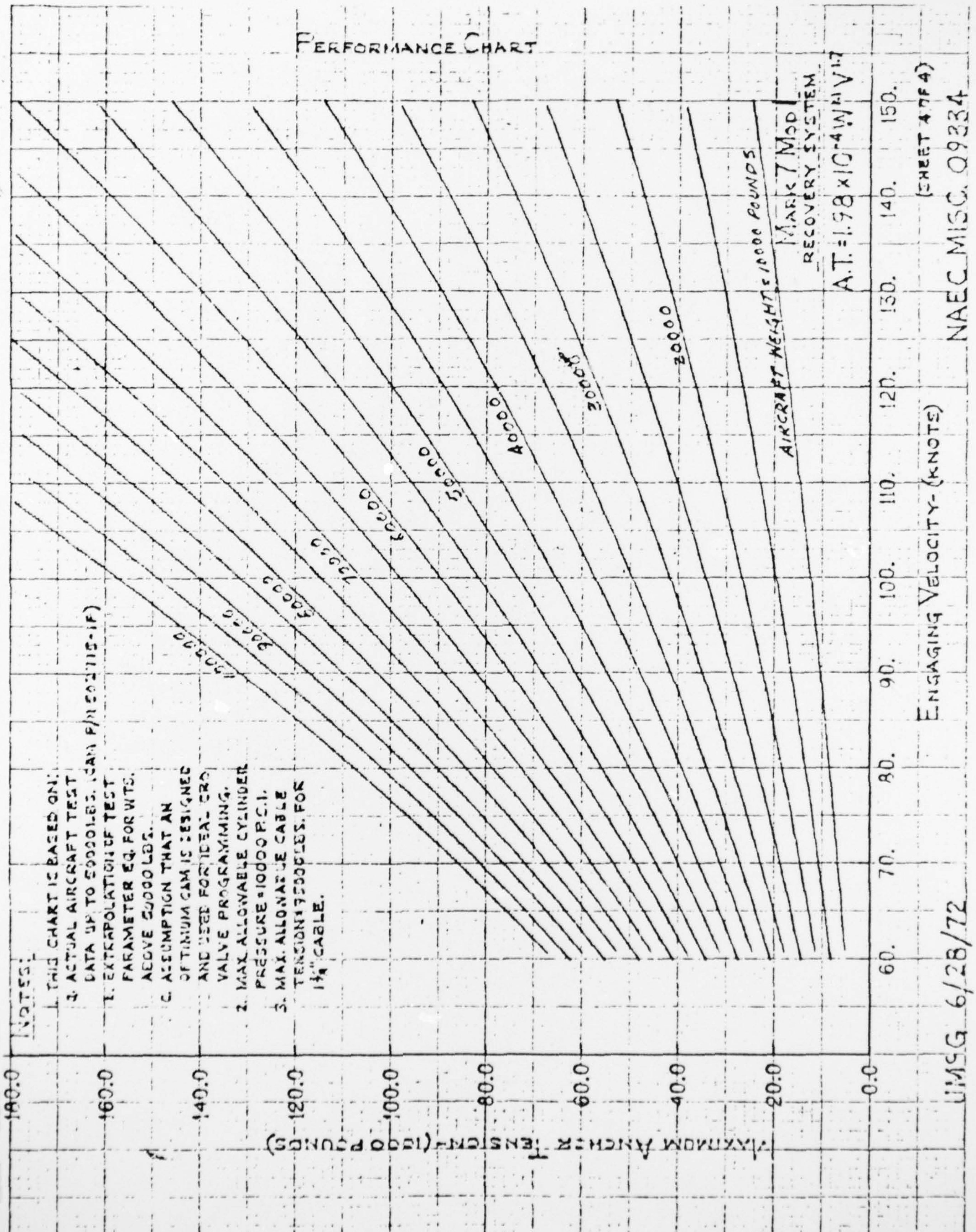
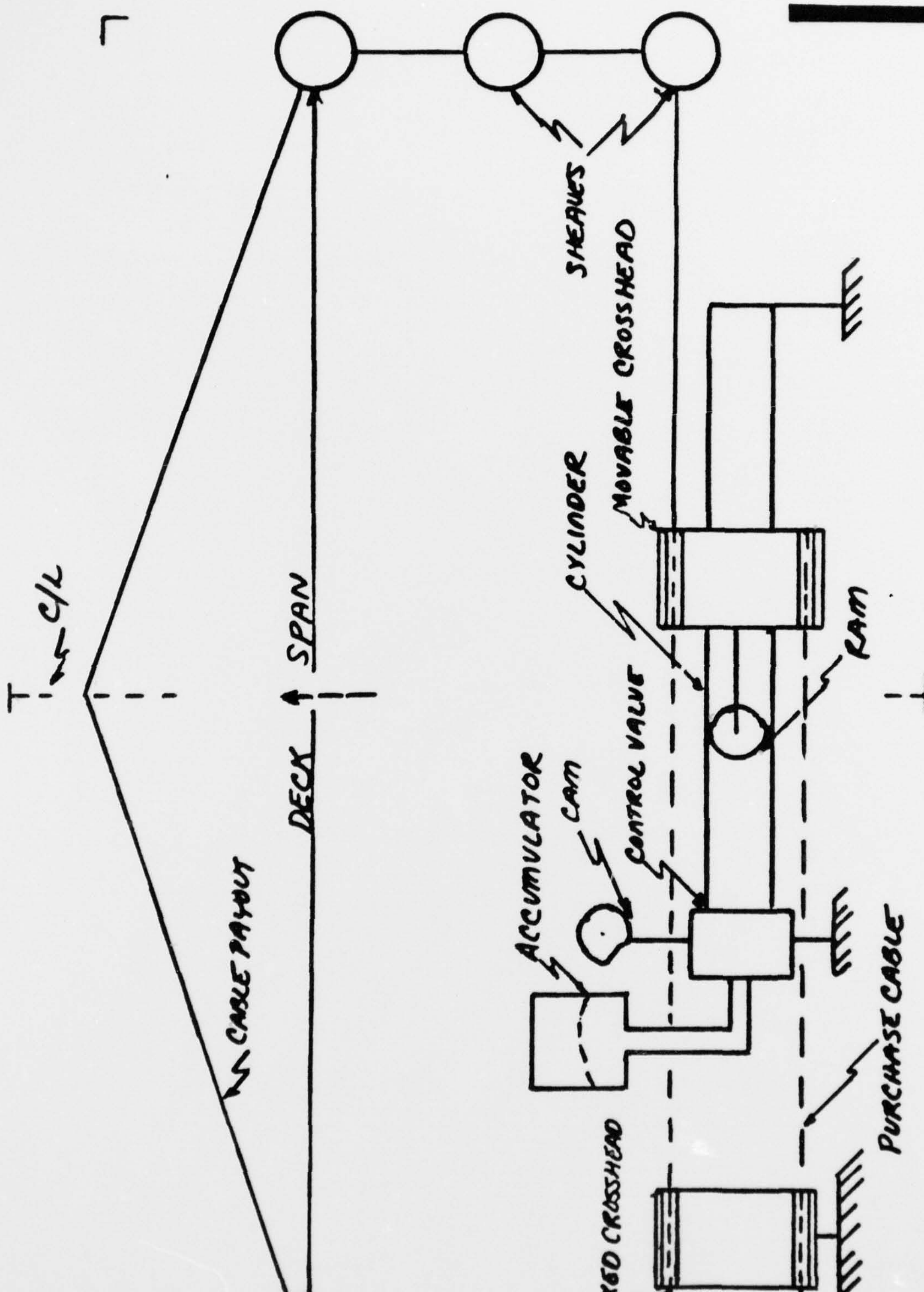

PERFORMANCE CHART
NOTES:
1. THIS CHART IS BASED ON:
A. ACTUAL AIRCRAFT TEST DATA UP TO 50000 LBS. (CAM P/N 502713-1F)
B. EXTRAPOLATION OF TEST PARAMETER EQ. FOR WTS. ABOVE 50000 LBS.
C. ASSUMPTION THAT AN OPTIMUM CAM IS DESIGNED AND USED FOR IDEAL CRO VALVE PROGRAMMING.
2. MAX. ALLOWABLE CYLINDER PRESSURE = 10000 P.S.I.
3. MAX. ALLOWABLE CABLE TENSION = 180000 LBS. FOR 1 3/4" CABLE.
100000
90000
80000
70000
60000
50000
40000
30000
20000
AIRCRAFT WEIGHT = 10000 POUNDS
MARK 7 MOD 1
RECOVERY SYSTEM
F = 3.24 × 10⁻² W V¹·⁵
MAX. HYDRAULIC HOOKLOAD - (1000 POUNDS)
ENGAGING VELOCITY - (KNOTS)
(SHEET 1 OF 4)
JMcG 6/23/72
NAEC MISC 09334

FIGURE 41


PERFORMANCE CHART
NOTES:
1. THIS CHART IS BASED ON:
a. ACTUAL AIRCRAFT TEST DATA UP TO 50000LBS. (CAN P/N 502715-1F)
b. EXTRAPOLATION OF TEST PARAMETER EQ. FOR WTS. ABOVE 50000LBS.
c. ASSUMPTION THAT AN OPTIMUM CAM IS DESIGNED AND USED FOR IDEAL CRO VALVE PROGRAMMING.
2. MAX. ALLOWABLE CYLINDER PRESSURE = 10000 P.S.I.
3. MAX. ALLOWABLE CABLE TENSION = 75000LBS. FOR 1¼" CABLE.
100000
90000
80000
70000
60000
50000
40000
30000
20000
AIRCRAFT WEIGHT = 10000 POUNDS
MARK 7 MOD 1
RECOVERY SYSTEM
A.T. = 1.98 × 10⁻⁴ W^.1 V^1.7
MAXIMUM ANCHOR TENSION - (1000 POUNDS)
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
60.
70.
80.
90.
100.
110.
120.
130.
140.
150.
ENGAGING VELOCITY - (KNOTS)
(SHEET 4 OF 4)
UMSG 6/28/72
NAEC MISC. 09334



SIMPLIFIED MARK 7
ARRESTING GEAR LAYOUT.

TABLE 4

CORRELATION OF MARK 7 RECOVERY SYSTEM PARAMETERS TO COMPUTER PROGRAM SIMULATION

PARAMETER			MOD 1		MOD 2		MOD 3		
SX(I)			K-5 CAM		K-15 CAM		K-30 CAM		
HH(I)			"		"		"		
D			"		"		"		
ST			118"		171"		183"		
DS			95'		95', 120'		95', 120'		
RR			18::1		18::1		18::1		
AP			314.16 sq"		268.8 sq"		314.16 sq"		
DIA			4"		4"		5"		
TMS			9		9		9		
CW			2		2		2		
SW			.0403 lb/in³		.0403 lb/in³		.0403 lb/in³		
G			32.2 ft/sec²		32.2 ft/sec²		32.2 ft/sec²		
C			1.1		1.1		1.1		
EX			-.217		-.217		-.217		
SK			210		210		210		
CV			$3.126(WT^{-.171})$		T.B.D.		T.B.D.		
EFF			$.201(ETA^{.084})$		T.B.D		$.148(ETA^{.1})$		
VAK			VARIES		VARIES		VARIES		
WT			"		"		"		
YF			"		"		"		
M			"		"		"		
THC			.4 to .65		.4 to .65		.4 to .65		

TABLE 5


```
      MARK 7 MOD 1 SIMULATION PROGRAM
      DIMENSION S(100),H(100)
      DIMENSION IR(9), IP(11),IV(8),IT(9),IF(7),IH(6),IS(6)
      DATA IR/'RAM STROKE-INCHES '/,IP/'CYLINDER PRESSURE PSI '/
      DATA IV/'VELOCITY-KNOTS  '/
      DATA IT/'CABLE TENSION LBS '/
      DATA IF/'HOCK LOAD LBS'/
      DATA IH/'LIFT-INCHES '/
      DATA IS/'TIME-SECONDS'/
      IC=0
      OPEN 25,1,900,8
      CALL PLOTS(0,0,6)
      DO 70 I=1,100
      READ(10,1)S(I),H(I)
      IF(S(I).EQ.999.) GO TO 72
   70 CONTINUE
   72 READ(10,2)VAK,WT,D
      READ(10,3)ST,DS,RR,AP,DIA,SW,G,SK
      READ(10,5)M,TI
      READ(10,6)C,EX
      READ(10,12)JJ
      READ(10,14)CV
      READ(10,16)EFF
      READ(10,18)FB
      READ(10,20)TMS,CW
      READ(10,22)THC
      VA0=84000.0
      L=1
      PR=0.0
      SR=0.0
      SX=0.0
      PX=400.0
      PA0=400.0
      RX=0.0
      EAB=0.0
      EFHL=0.0
      FHR=0.0
      FHL=0.0
      DT=0.0
      VX=VAK*1.689*12.0
      PO=2.0*TMS*ST
      RO=((((PO+DS/2.0)**2-(DS/2.0)**2))**.5)/12.0
      TH=THC*WT
      ETA=.0443*WT*(VAK**2)+(TH*RO)
      FD=(1.0-EFF)*ETA /(2.0*PO/12.0)
      CV=3.126*(WT**(-.111))
      EFF=.201*(ETA**.084)
      DO 21 I=1,M
      DT=DT+TI
      RS=RX
      RY=RS
      RX=RX+(VX*TI)
      DRX=RX-RY
      CL=((RX**2+(DS/2.0)**2))**.5
```

[redacted]

```
      SR=SX
      SY=SR
      SX=(CL-(DS/2.0))/(2.0*TMS)
      DSX=SX-SY
   33 IF (S(L).GE.SX)GO TC 75
      L=L+1
      IF(L.GT.JJ) GO TO 54
      GO TO 33
   75 HH      =H(L-1)+(H(L)-H(L-1))* (SX    -S(L-1))/((S(L)-S(L-1)))
      HA=HH/D .
      COST=RX/CL
      VLC=VX*COST
      VRA=VLC/(2.0*TMS)
      AO=1.1107*HA*(2*(DIA)-HA)
      CD=C*(AO**EX)*CV
      PA=(PAO*(VAO**1.4))/((VAO-(SK    *SX))**1.4)
      DPX=(SW/(24.0*G))*(VRA**2)*((AP/AO)**2)/((CD**2))
      PR=PX
      PY=PR
      PX=PA+DPX
      XPX=PX+PY
   76 FRA=PX*AP
      CT=((FRA)/(2.0*TMS*CW))+FD
      FHR=FHL
      FHY=FHR
      FHL=(2.0*CT*COST)
      DFHL=FHY+FHL
      EFHL=EFHL+(DFHL*DRX*.5)/12.0
      VX=((12.0*G)/WT)*TI*(TH-FB-FHL)+VX
      VFT=VX/1.689/12.0
      EAB=EAB+((XPX*.5)*DSX*(AP/12.0))
   51 WRITE(12,4)DT,SX,RX,PX,PA,CD,HA,VFT,AO,FHL,CT,EAB
      IC=IC+1
      WRITE(25(IC),4)DT,SX,RX,PX,PA,CC,HA,VFT,AO,FHL,CT,EAB
      IF(VX.LT.0.) GO TC 54
   21 CONTINUE
   54 EFC=EAB/ETA
      WRITE(12,8)TH,FD,RO,ETA,EFF,CV,EFC,EFHL
      WRITE(12,2)VAK,WT,D
   58 CONTINUE
      CALLAXIS(0.,0.,IR                          ,-17,10.0,0.,0.00,+20.)
      CALLAXIS(0.,0.,IP                            ,+21,6.0,90.,0.00,+2000.)
      DO 101 K=1,IC
      READ(25(K),4)DT,SX,RX,PX,PA,CD,HA,VFT,AO,FHL,CT,EAB
      X=SX/20.
      Y=PX/2000.
      IF (K.EQ.1) CALL FLCT(X,Y,3)
  101 CALL PLCT (X,Y,2)
      CALL PLOT (12.0,0.0,-3)
      CALLAXIS(0.,0.,IR                          ,-17,10.0,0.,0.00,+20.)
      CALLAXIS(0.,0.,IV                      ,+15,6.0,90.,0.00,+40.)
      DO 100 K=1,IC
      READ(25(K),4)DT,SX,RX,PX,PA,CD,HA,VFT,AO,FHL,CT,EAB
      X=SX/20.
      Y=VFT/40.
      IF (K.EQ.1) CALL PLOT(X,Y,3)
  100 CALL PLOT (X,Y,2)
      CALL PLOT (12.0,0.0,-3)
      CALL AXIS(0.,0.,IT,+17,4.0,90.0,0.00,+40000.)
      CALLAXIS(0.,0.,IR                          ,-17,10.0,0.,0.00,+20.)
```

```
      DO 102 K=1,IC
      READ(25(K),4)DT,SX,FX,PX,PA,CD,HA,VFT,AO,FHL,CT,EAB
      X=SX/20.
      Y=CT/40000.
      IF(K.EQ.1) CALL PLOT(X,Y,3)
  102 CALL PLOT (X,Y,2)
      CALL PLOT (12.0,0.0,-3)
      CALLAXIS(0.,0.,IR                    ,-17,10.0,0.,0.00,+20.)
      CALL AXIS(0.,0.,IF,+17,6.0,90.0,0.00,+40000.)
      DO 104 K=1,IC
      READ(25(K),4)DT,SX,RX,PX,PA,CD,HA,VFT,AO,FHL,CT,EAB
      X=SX/20.
      Y=FHL/40000.
      IF(K.EQ.1) CALL PLOT(X,Y,3)
  104 CALL PLOT (X,Y,2)
      CALL PLOT (12.0,0.0,-3)
      CALLAXIS(0.,0.,IR                    ,-17,20.0,0.,0.00,+10.)
      CALL AXIS(0.,0.,IH,+17,10.0,90.0,0.00,+.100)
      DO 106 K=1,IC
      READ(25(K),4)DT,SX,RX,PX,PA,CD,HA,VFT,AO,FHL,CT,EAB
      X=SX/10
      Y=HA/(.100)
      IF (K.EQ.1) CALL PLOT(X,Y,3)
  106 CALL PLOT(X,Y,2)
      CALL PLOT (22.0,0.0,-3)
      CALL AXIS(0.,0.,IS,-17,20.0,0.,0.00,+.250)
      CALLAXIS(0.,0.,IT,+17,10.0,90.0,0.00,+20000.)
      DO 110 K=1,IC
      READ(25(K),4)DT,SX,FX,PX,PA,CD,HA,VFT,AO,FHL,CT,EAB
      X=DT/.250
      Y=CT/20000.
      IF(K.EQ.1) CALL PLOT(X,Y,3)
  110 CALL PLOT (X,Y,2)
      CALL PLOT (22.0,0.0,-3)
      CALL AXIS(0.,0.,IS,-17,20.0,0.,0.00,+.250)
      CALLAXIS(0.,0.,IR,+17,10.0,90.0,0.00,+20.)
      DO 112 K=1,IC
      READ(25(K),4)DT,SX,FX,PX,PA,CD,HA,VFT,AO,FHL,CT,EAB
      X=DT/.250
      Y=SX/20.0
      IF(K.EQ.1) CALL PLOT(X,Y,3)
  112 CALL PLOT (X,Y,2)
      CALL PLOT (22.0,0.0,-3)
      CALL PLOT(0,0,999)
      STOP
    1 FORMAT(2F10.4)
    2 FORMAT(F6.1,F6.0,7F6.3)
    3 FORMAT(F6.1,F6.0,F3.0,F6.1,F4.1,F6.4,F6.2,F6.1)
    4 FORMAT(F7.3,F11.3,3F10.0,2F10.4,2F10.4,3F14.0)
    5 FORMAT(I4,F6.3)
    6 FORMAT(2F6.3)
    8 FORMAT(F8.1,3F14.0,3F9.3,F14.0)
   12 FORMAT(I2)
   14 FORMAT(F6.3)
   16 FORMAT(F6.3)
   18 FORMAT(F9.1)
   20 FORMAT(F4.1,F3.1)
   22 FORMAT(F5.3)
      END
```

A. LIST OF SYMBOLS IN ANALYSIS

SYMBOL	DESCRIPTION
A	Area of Pipe
ACGTY	Acceleration of Gravity
ACWGHT	Aircraft Weight
AREPTN	Area Piston
AREORF	Area Orifice
CBLPOU	Cable Payout
CBLTEN	Cable Tension
CONCOF	Contraction Coefficient
D	Diameter of Pipe
DECEL	Deceleration
DPMEC	Cylinder Pressure Drop
DSHCOF	Discharge Coefficient
FDRAG	Drag Force
FRAM	Ram Force
G	Acceleration of Gravity
HKLOAD	Aircraft Hookload
LIFT	Valve Stem Lift
MCHEFF	Mechanical Efficiency
MEC	Main Engine Cylinder
P	Pipe Pressure
PACCO	Initial Pressure Accumulator
PACC	Final Pressure Accumulator
PMEC	Pressure Main Engine Cylinder
Q	Discharge Rate
R	Reynolds Number
STROKE	Ram Stroke
THRUST	Aircraft Thrust
TIME	Time Increment
VALDIA	Constant Runout Valve Diameter
VELCOF	Velocity Coefficient
VELIN	Initial Velocity
VELOF	Final Velocity
VOLACO	Initial Accumulator Air Volume
VOLACT	Final Accumulator Air Volume
V_{1t}	Orifice Inlet Fluid Velocity
V_{2t}	Orifice Outlet Fluid Velocity
ρ	Density of Fluid

B. LIST OF SYMBOLS AS USED IN COMPUTER PROGRAM

SYMBOL	DESCRIPTION	UNITS
AO	Orifice Area	Square Inches
AP	Piston Area	Square Inches
C	Constant of Flow Equation	
CC	Contraction Coefficient	
CL	Cable Length	Inches
COST	Cosine (Θ)	
CW	Conventional Wrap	
CT	Cable Tension	Lbs.
CV	Velocity Coefficient	
D	Aircraft Dial Setting	
DIA	Valve Seat Diameter	Inches
DPX	Pressure Drop Across Orifice	PSI
DRX	Change In Runout	Inches
DSX	Change In Stroke	Inches
DT	Time Increments	Seconds
EAB	Energy Absorbed-Main Engine Cylinder	Ft.-Lbs.
EFC	Calculated Efficiency	
EFF	Mechanical Efficiency	
EFHL	Total Hookload Energy	Ft.-Lbs.
ETA	Total Energy of Engagement	Ft.-Lbs.
EX	Exponent of Flow Equation	
FB	Brake Force	Lbs.
FD	Drag Force	Lbs.
FHL	Hookload	Lbs.
FHR	Hookload	Lbs.
FRA	Ram Force	Lbs.
G	Gravitational Acceleration	Ft/SEC^2
HA	Valve Stem Lift	Inches
HH	Valve Stem Lift	Inches
JJ	Dummy Variable # of Lift Inputs	
K	Aircraft Thrust Variable	
M	Number of Program Time Increments	
PAO	Accumulator Pressure	PSI
PAC	Accumulator Pressure	PSI
PO	Cable Payout	Feet
PR	Cylinder Pressure	PSI
PY	Cylinder Pressure	PSI
PX	Cylinder Pressure	PSI
RO	Runout	Feet
RX	Runout	Inches
RY	Runout	Inches
RS	Runout	Inches
RR	Reeve Ratio	

B. LIST OF SYMBOLS AS USED IN COMPUTER PROGRAM (CON'T)

SYMBOL	DESCRIPTION	UNITS
SK	Dummy Variable Accumulator Pressure	
ST	Ram Stroke	Inches
SR	Ram Stroke	Inches
SX	Ram Stroke	Inches
SY	Ram Stroke	Inches
SW	Specific Weight - Ethylyne Glycol	Lbs./In.^{3}
TH	Aircraft Thrust	Lbs.
THC	Aircraft Thrust Variable	
TI	Time Increments	Seconds
VAO	Accumulator Air Volume	Cubic Inches
VAK	Velocity of Aircraft Engagements	Knots
VLC	Cable Velocity	Inches/SEC
VRA	Ram Velocity	Inches/SEC
VX	Aircraft Velocity	Inches/SEC
WT	Aircraft Weight	Lbs.
XPX	Twice Cylinder Pressure	PSI

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